Chapter 1
Elementary and Secondary Education

Contents

Highlights

International Comparisons

- **In a 1995 international comparative study on mathematics and science achievement, U.S. students performed comparatively better in science than in mathematics and better at the fourth grade level than at the eighth grade level.** U.S. fourth graders were significantly outperformed in science only by students in South Korea. The United States performed least well, when compared with other nations, in grade eight mathematics.

- **When compared with other countries, U.S. mathematics and science textbooks contain many more topics and much repetition of material.** For example, U.S. general mathematics textbooks for eighth grade students contain an average of 36 different topics, compared with 8 topics in Japanese and 4.5 topics in German texts. In addition, there is evidence that in the United States, eighth grade mathematics is pitched at a lower level than in higher achieving countries. While U.S. students are still working on "high-end arithmetic," their peers in other countries are studying algebra and geometry.

Student Performance

- **In national assessments of mathematics and science learning, students are performing as well as—if not better than—the students of 25 years ago.** Nine-year-olds and 13-year-olds scored higher on mathematics and science tests in 1996 than they did in 1973, while performance of 17-year-olds has remained about the same. However, little of the overall improvement in test scores that occurred during this period has come about during the 1990s.

- **There is little evidence of a difference in the mathematics and science proficiency of girls compared with boys** on national assessments of educational progress. The slight difference that has been identified is confined to students in the 12th grade.

- **As of 1996, large differences remain at all grade levels in the achievement scores of black and Hispanic students as compared with whites and Asians/Pacific Islanders.** Native American students generally scored closer to the national average than did blacks or Hispanics.

Curriculum and Instruction

- **There have been large gains in the proportion of students taking advanced mathematics and science courses in high school since the early and mid-1980s—gains that often include students from underrepresented groups.** In the class of 1994, close to 70 percent of students had completed geometry, 58 percent completed algebra 2, and 9 percent took calculus. Over 90 percent of seniors completed biology, over half completed chemistry, and about one-quarter took physics.

- **Internet access in schools has increased substantially in recent years.** As of fall 1996, 65 percent of public schools reported access to the Internet, a gain of 30 percentage points over 1994 figures. Internet access was more likely in secondary than in elementary schools, in more affluent than less affluent schools, and in schools with low to moderate minority enrollments than in schools with high minority enrollments.

Teachers and Teaching

- **The vast majority of elementary school teachers earn college degrees in education rather than in specific disciplinary areas.** High school teachers were much more likely to possess science and mathematics degrees: 41 percent had earned a degree in mathematics, compared with just 7 percent of middle school teachers. In science, 63 percent of high school science teachers and 17 percent of middle school science teachers possessed a science degree.

- **Many middle school mathematics and science teachers fall short in meeting recommendations for coursework preparation made by national associations of teachers.** Only 7 percent of middle school mathematics teachers have taken courses in all of the recommended areas and about one-third have completed none of the coursework recommendations. Forty-two percent of middle school science teachers meet the science recommendations in full.

- **All too frequently, teachers are assigned to teach classes outside their fields.** The problem is particularly acute in mathematics. In the 1990/91 school year, 27 percent of students in grades 7 through 12 had a mathematics teacher without at least a minor in mathematics or mathematics education. Out-of-field teaching is more common at middle schools than high schools.

Introduction

Chapter Background

Educators in elementary and secondary schools across the nation are struggling to improve and redesign mathematics and science education so that all students are well-prepared for the beginning of a new millennium. Policymakers are confronted with growing determination that a solid foundation in mathematics, science, and technology is essential not only to the economic but also to the social well-being of the nation. Indeed, a task for today's policymakers, parents, and communities is to ensure that all students are graduated from high school with a quality education that will enable them to contribute productively to society. Toward this end, the United States has set, as a matter of national policy, the goal of its students being first in the world in mathematics and science achievement by 2000.

However, national and international indicators of educational progress suggest that the country is still far from its goal, despite a growing reform movement aimed at achieving excellence and equity in education. Unresolved issues concerning the performance of students and teachers, the quality of instructional materials and teaching, and access to quality education for all students are matters still very much at the center of local, state, and national education agendas. Nevertheless, indications of forward movement abound: students are taking more advanced courses in science and mathematics, teachers are more aware of the need to change their conceptions of teaching and learning, and student achievement in mathematics and science has largely returned to or exceeded the levels set in the 1970s.

The spark for much of the current reforms came from early work in setting standards performed by professional associations of mathematics and science educators. In mathematics, the National Academy of Sciences laid out the broad outlines of mathematics reform in *Everybody Counts: A Report to the Nation on the Future of Mathematics Education* (MSEB 1989). The National Council of Teachers of Mathematics (NCTM) followed with two reports that made more specific recommendations—*Curriculum and Evaluation Standards for School Mathematics* (NCTM 1989) and *Professional Standards for Teaching Mathematics* (NCTM 1991).

During this same period, consensus on new directions for science education was beginning to develop, though actual national standards were some years away. By 1993, the American Association for the Advancement of Science had issued two publications, *Science for All Americans* (AAAS 1989) and *Benchmarks for Science Literacy* (AAAS 1993), and the National Science Teachers Association produced *Scope, Sequence and Coordination of Secondary School Science* (NSTA 1992). These reports, as well as others, led to a national dialog on science standards resulting in the National Academy of Sciences' *National Science Education Standards* (NRC 1996).

The standards for mathematics and science education share many core ideas: high expectations for all students; in-depth study and understanding of core concepts; emphasis on hands-on tasks that promote active engagement with the subject matter; and a strong focus on reasoning, problem solving, and the ability to apply learning within broader contexts.

The standards in both subjects view teachers as the critical agents that enable students to meet these more demanding levels of performance. However, a large proportion of current mathematics and science teachers were trained when conceptions of teaching and learning were very different from today. Consequently, both sets of standards emphasize the importance of professional development for teachers. Previously offered as a sporadic set of brief workshops to train teachers in specific skills, professional development is now portrayed as a career-long process of continuously updating teachers' mathematics and science knowledge and teaching skills (Darling-Hammond 1994a). And although some school systems, schools, and teachers have begun to adopt practices consistent with the standards, mathematics and science educators recognize that full implementation of standards-based reform will take much more time (Jones et al. 1992; Lindquist, Dossey, and Mullis 1995; and NSF 1996).

Like professional development, equity remains an important challenge for educational reformers in mathematics and science education. At its base, equity means that each and every student has access to quality education regardless of background, race, ethnicity, or location. Some of the building blocks for equity are:

- the necessary materials, funding, and resources for standards-based learning to thrive in schools;
- fully qualified teachers who are knowledgeable about the subjects they teach; and
- appropriate instructional strategies, curricula, and tools for assessing student performance (Darling-Hammond 1992).

One of the critical issues currently facing educators is how to achieve equity and excellence amid the complexities born of an increasingly diverse national makeup. Of the 45 million children enrolled in elementary and secondary schools in 1994, approximately 15 million are ethnic or racial minorities and 6 million come from homes where English is not the primary language spoken (NCES 1996b).

There are still more challenges: how to make effective use of the information technologies that are now commonplace in homes and workplaces as tools for reforming education and improving teaching and learning productivity; how to ensure consistency in approach and quality among instructional materials, teaching, assessment of student learning, and policies formed at district or state levels; and, finally, how to continue learning how to improve—and what works and doesn't work in improving—the quality of education.

Clearly, the role education plays in our personal lives and in the nation's well-being has grown over the years. And the challenges in mathematics and science education—and in all school subjects, for that matter—are before us as educators, students, parents, and community members. And although these challenges may differ from those of years past, it is not clear that there are necessarily more of them, nor is it certain that they are any more daunting than they once were. It may be that we are more concerned and know more about mathematics, science, and technology education in this nation than we did 20 or 30 years ago. As shown in this chapter, what *is* certain is that we have a stronger research base and a deeper, more far-reaching set of national and international indicators of performance than ever before. (See "Measuring the Performance of the Education System.")

Chapter Organization

This chapter is organized into three main parts: first, a detailed description of student achievement in mathematics and science is provided; second, curriculum and instruction are examined; and third, teachers and teaching are addressed. These latter two parts are presented because they are the components of the education process thought to have the greatest direct influence on student achievement. The chapter concludes with a summary of trends in these three areas and an interpretation of what this may mean for educational progress.

Under the student achievement section, the performance of U.S. students in both national and international contexts is examined in order to address the following questions:

- Have mathematics and science achievement in the United States improved in the last decade or more?
- Is the achievement of all students, regardless of demographic group, improving?
- How have the coursetaking patterns of U.S. students changed in the last decade and with what effects on achievement?
- How do U.S. students compare with students in other nations in mathematics and science achievement?

The second major section of this chapter, on curriculum and instruction, focuses on the following questions:

- How do the mathematics and science curricula experienced by U.S. students compare with curricula in other countries?
- What are the similarities and differences in the instructional practices and resources used in U.S. and other classrooms?

The third major section of the chapter examines the background of U.S. mathematics and science teachers in national and international contexts. The discussion centers on these questions:

- Are teachers well-prepared for teaching mathematics and science?
- What are teachers' views about teaching mathematics and science?
- What effect is the standards-based reform movement having on the profession of teaching?

Many national and international data sources—all based on national probability samples—have been mined in writing this chapter. The first section of this chapter can be examined from a number of perspectives using a variety of data sources. The discussion here draws on three primary sources: the National Assessment of Educational Progress (NAEP), the Third International Mathematics and Science Study (TIMSS), and the High School Transcript Studies. NAEP is a reliable indicator of achievement for U.S. students. Since the early 1970s, NAEP has conducted trend assessments every two years covering mathematics, science, reading, and more recently, writing. These assessments draw on nationally representative samples of 9- 13-, and 17- year-olds. To date, eight trend assessments have been conducted in mathematics and nine in science.

NAEP also conducts subject matter assessments periodically on a wider range of subjects including history, geography, civics, computer competence, art, and music. Subjects are covered on a rotating basis so that in one assessment, the focus may be on mathematics and science, and in the next, on history and social studies. These assessments draw on nationally representative samples of students in grades 4, 8, and 12 rather than the age groups used in the trend studies. Items in the periodic subject matter assessments are revised from time to time to incorporate new assessment strategies and reflect prevailing professional judgments about what students in a particular grade should be learning. The items used in trend assessments are fixed, so that performance in basic areas of skill and knowledge can be traced over time, even as curriculum emphases change. Results of these two kinds of NAEP assessments are not directly comparable because of these sampling and content differences.

The second source of student performance data used in this chapter, TIMSS, compares the mathematics and science achievement of elementary and secondary students in the United States with the achievement of students in other countries. TIMSS was conducted in 1994-95 by members of the International Association for the Evaluation of Education. It is the largest and most ambitious undertaking of its kind. Forty-five nations took part in TIMSS at the middle school level (seventh and eighth grades), and 27 at the elementary school level (third and fourth grades).[1] Achievement data and background information were collected from students in each country. Teachers and principals supplied information about instructional resources, practices, staffing, course content, and views of mathematics and science teaching. Curriculum guides and textbooks from 46 nations were analyzed to provide information on the content and skills students in different countries are expected to learn in each grade. Mathematics lessons were videotaped in a sample of eighth grade classrooms in the United States, Japan, and Germany to document differences and similarities in the content presented and the instructional approaches used.

TIMSS results have been published in several reports. Results of curriculum studies are presented in three reports: *A Splintered Vision: An Investigation of U.S. Science and Mathematics Education* (Schmidt, McKnight, and Raizen

[1]At the time this chapter was written, 12th grade TIMSS results had not been released.

Measuring the Performance of the Education System

Few countries have a truly unitary national education system. Many are aggregations of smaller (e.g., regional) subsystems coordinated by an overall national entity. Most of the 49 countries that participated in TIMSS, for example, have fewer than five subsystems. In the case of some nations—such as the United States—these subsystems (i.e., states) are more or less autonomous, with only indirect influence exercised at the national level (Schmidt, Raizen et al. 1997).

Schmidt, Raizen et al. point out that policymaking is affected by the degree of complexity within the national education system. Countries with a unitary system can make policy about curriculum and decisions about system performance measurement with greater ease than countries with more complex, decentralized systems (Schmidt, Raizen et al. 1997).

The U.S. educational "system," then, is more accurately a multiplicity of systems that can be described from numerous perspectives. It is useful to keep various dimensions simultaneously in mind when thinking about how to measure its performance. Decisions about learning practices are made and affected by networks of practitioners, researchers, policymakers, parents, and community and business leaders, as well as by students. Decisions about what to teach are reflected in curriculum frameworks and materials, instructional practices, teachers' professional development, and student performance assessments. Decisions about resource use are shared by several levels of government: federal, state, and local—within which are school districts, schools, grade levels, and classrooms—across a country of 268 million people.

The states are the primary agents of education as delegated by the U.S. Constitution. However, a long tradition of local decisionmaking authority about what and how to teach is distributed among parent and teacher groups and school boards for each autonomous school district. No matter how the system is portrayed, the difficulty in measuring it is based in its complexity—a web spanning the nation woven within the boundaries of individual states and communities in the form of people, places, behaviors, and ideas.

Compared with countries around the world, the U.S. education system is distinguished by its size, organization, and—above all else—the diversity of the students it serves. In the 50 states and 11 territories, there are over 14,000 school districts and 87,000 public schools (NCES 1996b).

While trends in student performance and coursetaking, characteristics of curriculum and instruction, and preparation and qualifications of teachers may describe the condition of various elements of the system, they do not necessarily encapsulate the performance of the elements as they interact, work in tandem, or change across the system. How much and in what direction the system components move together (or co-vary), is an indicator of systemwide change (Chubin 1997).

The demand is increasing for valid and reliable indicators in accounting for the use of public resources and in sharing knowledge with parents, educators, and policymakers.

Many of these "systemic" features are affective or qualitative, such as system leadership, partnerships, alignment of policies and practices, and student and teacher creativity. Such systemic qualities have not yet been adequately operationalized into acceptable indicators of a system's performance.

Consistent with this systems notion, the Consortium for Policy Research in Education has developed a potential model for evaluating systemwide change in the context of a Philadelphia reform project sponsored by a large collection of public and private funders. The evaluators have created a scorecard that allows them to make judgments about the degree of change across various elements of the Philadelphia reform, thus enabling them to portray the movement of the system as a whole (CPRE 1996).

New approaches to measurement and measurement tools will be needed to investigate the synergy (or lack thereof) among system components. What is needed are indicators of how these various elements work together or apart, what factors characterize the system, and what their effects are on student achievement. Indeed, NSF has funded several research studies that support these new measurement directions. One such study, performed by Cohen and Hill (1997), has examined the interrelationship among teacher professional development, the use of curriculum materials, and the assessment of student performance in fourth and eighth grade mathematics classes in the state of California. What they found supports the power of measuring the combined effects of system components.

Cohen and Hill found that teachers who participated in professional development based on curriculum materials relevant to reform goals were much more likely than other teachers to report teaching practices aligned with these goals. Moreover, their results suggest that "when educational improvement is focused on learning and teaching academic content, and when curriculum for improving teaching overlaps with the curriculum and assessment of students, teaching practice and student performance are likely to improve" (Cohen and Hill 1997). In other words, Cohen and Hill have begun to measure the synergy among system elements as they relate to instructional materials—and have found evidence that such synergy results in improved student performance.

In general, the U.S. curriculum is not consistent with those of other countries that performed well on the TIMSS assessment. When compared with other countries, U.S. mathematics and science curricula are less focused and include far more topics than is common internationally. The topics—especially in mathematics—tend to remain in the curriculum for more grade levels than is the practice in other countries (Schmidt, McKnight, and Raizen 1997).

The Cohen and Hill study, TIMSS, and other studies supported by NSF are indicative of the research that is needed to address systemic issues. Indeed, much of the TIMSS data is yet to be analyzed, and the richness of the study holds forth the promise of more lessons to be learned. More research on systemwide change in larger and different settings is needed to advance and refine these findings.

This chapter begins to move in the direction of examining systems, both national and statewide, of mathematics and science education at the elementary and secondary level. The various measures of student performance, however imperfect, provide some evidence of system outcomes. There are still many more indicators to be developed that will aid local decisionmakers, state and federal policymakers, educators, parents, and their community partners. Although we do not yet have all of the desirable information, we have much more than we once did, more in mathematics and science than in other subject areas, and more at the elementary and secondary levels than at the postsecondary level and beyond.

1997) and two volumes—one for mathematics and one for science—that present international comparisons, *Many Visions, Many Aims* (Schmidt, McKnight et al. 1997; and Schmidt, Raizen et al. 1997). International achievement and survey results are available in four volumes, one for each subject by grade (Beaton, Mullis et al. 1996; Beaton, Martin et al. 1996; Martin et al. 1997; and Mullis et al. 1997). Results from the survey of eighth grade U.S. teachers are presented in *Mathematics and Science in the Eighth Grade* (Williams et al. 1997). Syntheses of U.S. findings from component TIMSS studies are published in two volumes of *Pursuing Excellence*, one for fourth grade (NCES 1997c) and one for eighth grade (NCES 1996c).

A third major source of information about student performance is the 1994 High School Transcript Study, which is based on the records of over 25,000 seniors who graduated from high school that year. The transcript study reports information such as the mean number of credits earned in each subject field and the percentage of students earning a given number of credits in particular subjects (NCES 1997e).

The discussion of curriculum and instruction is based largely on data from the TIMSS curriculum analyses, video observational studies, and teacher questionnaires. The technology portion of this section is drawn from a recent survey on the status of advanced telecommunications in public elementary and secondary schools (NCES 1997a).

The third section of this chapter, on teachers and teaching, is based on comparisons of data from the TIMSS teacher questionnaires with results from the National Survey of Science and Mathematics Education (NSSME) conducted during the 1993/94 school year (Weiss, Matti, and Smith 1994). NSSME, which was initiated in 1977 and updated in 1985, is one of the most comprehensive sources of detailed information on the preparation and classroom practices of mathematics and science teachers. The discussion of teacher qualifications is supplemented by data from questionnaires administered as part of the 1993/94 Schools and Staffing Survey. (See NCES 1996a.) Information on teachers' efforts to implement educational standards in their classrooms is drawn from a school reform survey conducted in spring 1996 (NCES 1997d).

Do Policies and Socioeconomic Factors Play a Role in Achievement?

Performance differences among states may reflect any number of factors, including differences in educational policy and in demographic characteristics. The 1996 Policies and Practices Survey, conducted by the Council of Chief State School Officers, provides information on several useful indicators of instructional quality: number of mathematics and science credits required for graduation, status of standards implementation, and requirements for teacher licensing (CCSSO 1996). An examination of these variables revealed no systematic patterns that might account for performance differences among states.

In the area of social and economic factors, there are suggestions from some studies that differences in "opportunity" may be linked to differences in student background and other socioeconomic variables. Several studies have shown that poor and minority students are more likely to attend schools with severely limited resources and less well-prepared teachers, more likely to be sorted into low academic tracks that limit their access to advanced mathematics and science courses, and less likely to attend schools that offer these advanced courses (Oakes, Gamoran, and Page 1992).

Performance in mathematics and science may also be influenced by other demographic characteristics such as family background. A study that examined the relationship between increases in achievement and changes in family characteristics in the 1980s found that gains made by white students could be completely accounted for by improved family circumstances over the years examined, but only one-third of the gains made by black students—and virtually none of the gains made by Hispanic students—were explained by these factors (Grissmer et al. 1994).

Student Achievement

Trends in U.S. mathematics and science achievement are mixed, but somewhat positive on the whole. Students are more often taking advanced courses in both subjects, and their performance is slightly improved from, or no worse than, the performance levels set in the 1970s. Larger shares of students—including those from underrepresented racial and ethnic groups—are meeting basic levels of proficiency in both subjects than in past years, although wide gaps in achievement remain between students from these groups as compared with whites and Asians. (See "Do Policies and Socioeconomic Factors Play a Role in Achievement?")

Several studies have attributed differences in mathematics and science achievement to the types of courses students complete (Jones et al. 1992 and Gamoran 1986). Acting on the premise that more high-level courses will result in higher achievement, many states and school districts raised graduation requirements in mathematics and science (as well as in other core subjects) following publication of *A Nation at Risk* by the National Commission on Excellence in Education (1983). Two years before its release, only nine states required two or more years of science and two or more years of mathematics. Fifteen years later, 42 states had put these stricter graduation requirements into place (CCSSO 1996).

Comparisons of U.S. achievement with that of other countries provide another important perspective on how well students and schools are performing. International comparisons reveal that, although U.S. students are performing relatively well in science compared with the rest of the world, there remains much room for improvement in mathematics. The performance of students in high-scoring nations demonstrates what is possible for students to achieve at the elementary, middle, and high school levels in this or any country. And, in so doing, student performance overseas provides information educators and policymakers can use in setting appropriate policies, expectations, and goals. Unfortunately, there is no reliable way to determine if the U.S. standing has improved or worsened in recent years. Comparisons with earlier assessments cannot be made because of methodological differences between the studies, differences in the content tested, and changes in countries participating in these tests. (For further information on performance assessments in general, see "Assessing Student Performance.")

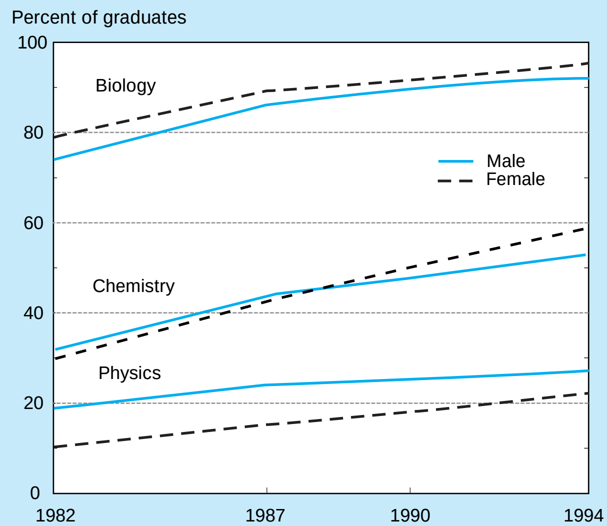
Science Coursework

High school graduates in the 1990s are much more likely to have completed advanced courses in the sciences such as biology, chemistry, and physics. In 1994, 93 percent of graduates had taken biology compared with 77 percent of 1982 graduates. Similarly, more than half now take chemistry compared with less than one-third in 1982, and one in four now complete physics compared with about one in seven in 1982. Although they remain a minuscule fraction of the total, the proportion of students completing advanced placement courses in these science subjects has also increased.

Female graduates are more likely to have taken biology and chemistry in high school than male students, but less likely to have taken physics. This represents a change in the coursetaking patterns of young women as compared with young men. In 1982, female graduates were about as likely as males to have taken chemistry and substantially less likely than males to have taken physics. (See figure 1-1.)

Students from racial and ethnic groups underrepresented in science made substantial gains in the proportions taking advanced science courses. More than 90 percent of blacks, Hispanics, and Native Americans now complete high school having taken biology. In chemistry, the proportion of blacks completing the course doubled (from 22 to 44 percent), rates for Hispanics nearly tripled (from 16 to 46 percent), and completions by Native Americans rose by more than half (from 26 to 41 percent) between 1982 and 1994. Similarly, progress was made in physics coursetaking between 1982 and 1994, although the proportions of students from black and Hispanic groups remain less than 20 percent. The proportion of blacks taking physics almost doubled, and the percentage of Hispanics nearly tripled. No discernible increase in the proportion of Native Americans completing physics was detected over the 12-year period. All in all and despite the progress, there remains a substantial gap in the proportions of blacks, Hispanics, and Native Americans who take chemistry and physics compared with Asian Americans/Pacific Islanders and whites. (See figure 1-2.)

Figure 1-1.
Percentage of high school graduates earning credits in selected science courses, by sex



See appendix table 1-1. *Science & Engineering Indicators – 1998*

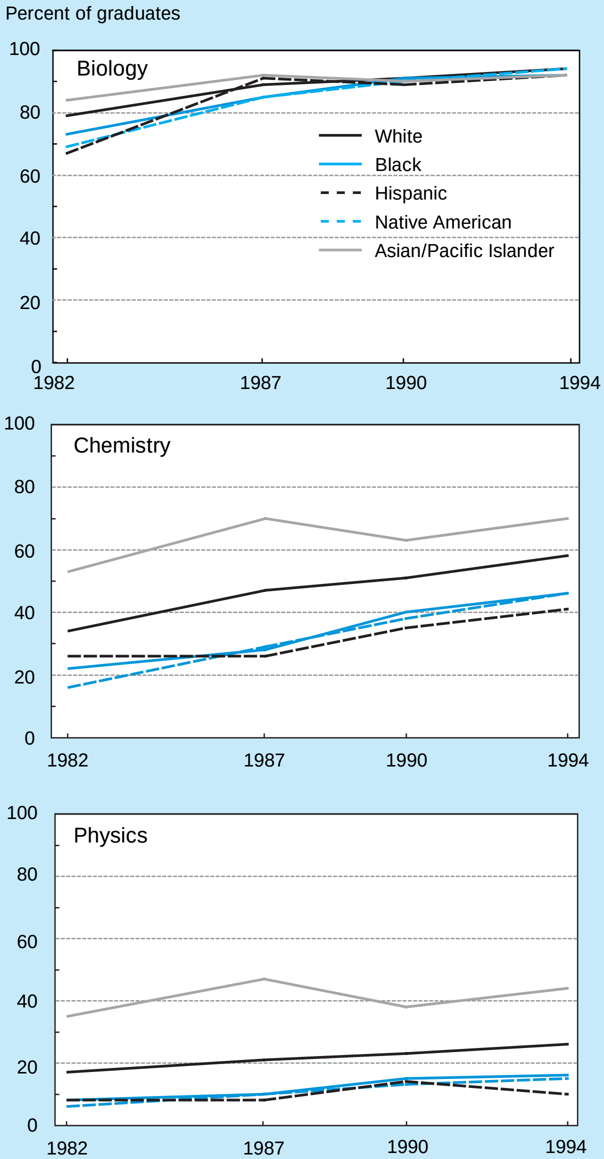
Science Proficiency

In the 1970s, science proficiency scores of elementary and secondary students remained largely flat, but—beginning in the mid-1980s—students began to show improvement. (See figure 1-3.) By the mid-1990s, 9-year-olds and 13-year-olds were scoring slightly higher than their counterparts of 1973, and the scores of 17-year-olds had rebounded to the higher 1973 levels.

Of all school subjects, science in particular has been a sticking point in comparisons of student performance between sexes and among racial and ethnic groups. The underrepresentation of women in the science, mathematics, and technology workplace makes sex-based achievement differences a continuing concern among educators. However, national assessments of educational progress reveal that there are no real differences in science proficiency between 9-year-old girls and boys. Thirteen- and 17-year-old boys edge out girls in science performance, but this difference is small and has narrowed for 17-year-olds since the early 1970s. (See appendix table 1-3.)

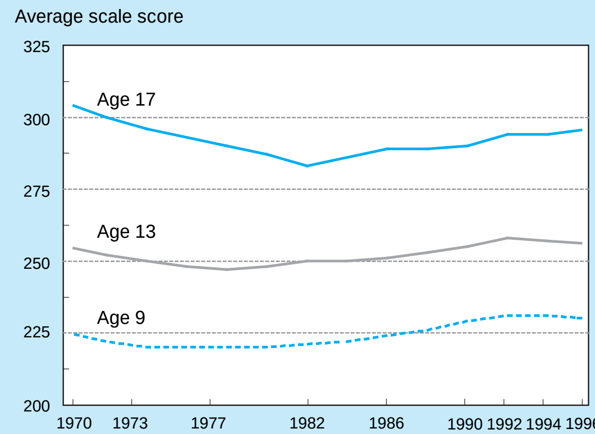
Of much more compelling concern at the moment are the racial and ethnic differences that remain in science achievement. The performance of black and Hispanic students at all age groups was far below that of whites in 1996, as has been the case for decades. And although the difference between black and white students has declined for 9-year-olds and 13-year-olds since the 1970s, the disparity for 17-year-olds remains virtually unchanged. There has been no change in the difference between Hispanic and white achievement at any age. Average test scores of Native American students based on a related 1996 science assessment were closer to the

Figure 1-2.
Percentage of high school graduates earning credits in science courses, by race/ethnicity



See appendix table 1-2. *Science & Engineering Indicators – 1998*

Figure 1-3.
National trends in average NAEP scale scores in science at ages 9, 13, and 17



NOTE: NAEP is the National Assessment of Educational Progress.

See appendix table 1-3. *Science & Engineering Indicators – 1998*

national average than is the case for black and Hispanic students. Lower achievement is thought to be one reason why minority students make different elective course choices or are screened out of opportunities for more advanced study in science (Oakes 1990).

It is also useful to examine achievement differences across states. Science proficiency was reported on a state-by-state basis for the first time in 1996. (See "The Making of a New Science Assessment.") Figure 1-4 shows how eighth grade students in each participating state compared to the national average. In general, most of the high-scoring states were in the Central, Western, and New England regions of the country, while the majority of the lower performing states were in the Southeast.[2]

Across states, racial and ethnic differences in science proficiency were apparent, and these cross-state differences followed many of the same patterns as overall state-by-state test score differences. That is, students of all races and ethnicities tended to score more highly in states with high overall science performance than in states with consistently lower performance. However, the magnitude of the difference in average scores varied to a surprising degree from one state to another. Average science scores for Hispanic and black populations, for example, fluctuated enormously across different states.

Black students scored below the national average in science in all states. Blacks scored highest in Colorado, but this score was not as high as even the lowest average for whites of any state. The largest achievement gaps between black and white students were in Wisconsin, Connecticut, and New York. With the exception of New York, Hispanic students in states known for their large Latino populations—California, Texas, Florida, and New York—achieved the national overall average score for Hispanic science proficiency.

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[2]States were classified as follows (Reese et al. 1997):

- **Northeast**—Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and (Northern) Virginia;
- **Southeast**—Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, (Southern) Virginia, and West Virginia;
- **Central**—Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin; and
- **West**—Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oklahoma, Oregon, Texas, Utah, Washington, and Wyoming.

The Making of a New Science Assessment

In 1996, in order to better measure the effects of current approaches to science education, the U.S. Department of Education made major changes to subject matter assessment in science through its National Assessment of Educational Progress. The new test represents a departure from earlier ones both in the science that is tested and in the way it is tested. First, factual knowledge is assessed within meaningful scientific contexts. Second, level of performance depends not only on knowledge of facts, but also on the ability of students to integrate this information into a larger body of knowledge, and the capacity of students to use the reasoning processes of science to develop their understanding of the natural world.

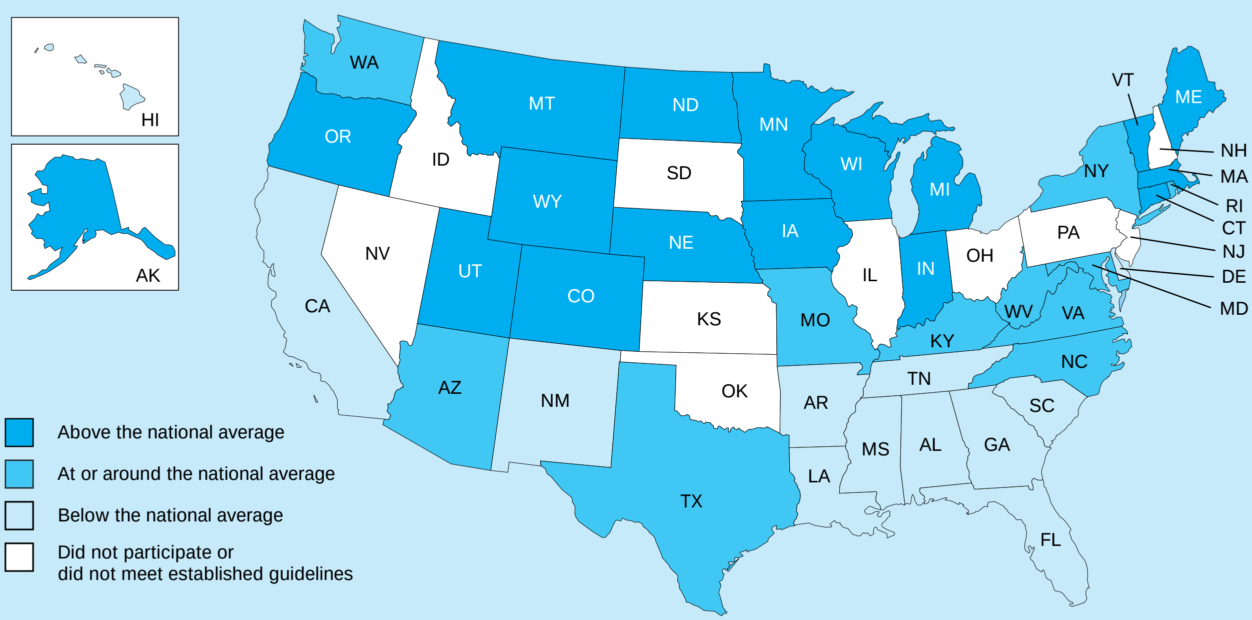
The 1996 assessment used a variety of methods for measuring student performance:

- ♦ multiple-choice questions that assess students' knowledge of important facts and concepts and that probe their analytical reasoning skills;
- ♦ written response questions that explore students' abilities to explain, integrate, apply, reason about, and communicate scientific information; and
- ♦ hands-on tasks that measure students' abilities to make observations, perform investigations, evaluate experimental results, and apply problem-solving skills.

The framework from which the assessment was constructed was developed through a consensus process that brought together science teachers, curriculum experts, other educators, policymakers, members of the business community, and the general public. The framework divides science into three major fields: earth, physical, and life sciences. It also assesses such mental processes important for scientific thinking as conceptual understanding, practical reasoning, and investigation by experimentation.

Although the changes introduced in 1996 mark a meaningful and rich new source of information on student performance, comparisons cannot be made with results of earlier assessments. Consequently, this chapter relies on the NAEP trend assessments in science in making comparisons of student performance over time.

Figure 1-4.
NAEP grade 8 average scale scores in science, by state: 1996



NOTE: NAEP is the National Assessment of Educational Progress.

See appendix table 1-4.

Science & Engineering Indicators – 1998

Assessing Student Performance

Assessment—in the educational context—is the *process* of gathering evidence about a student's knowledge of, ability to use, and disposition toward some subject matter with the purpose of making inferences from that evidence for a variety of ends. A test is a measuring *instrument* for evaluating and documenting those outcomes. Simple enough to describe, assessments are not simple to devise nor have they proven easy to integrate effectively within the instructional programs of large education systems. At their conceptual base, assessments are a complex endeavor and the inferences that can be made from them for individual students, teachers, schools, as well as whole educational systems need to be considered with numerous caveats.

There are differences of opinion among educators, researchers, and policymakers about the design and use of standardized and performance-based assessments.

Traditional standardized tests—usually of the short answer variety that are administered, scored, and interpreted in a consistent manner wherever and to whomever given—are the tests that are most often now in place in states and at the national level. But they do not necessarily measure well those aspects of learning such as creativity, deep conceptual understanding, and the ability to apply learning in a number of contexts deemed important or appropriate by many of today's educators. Traditional tests of student performance (answering a question with a single correct short answer) are an efficient method to assess large numbers of students at low cost. However, traditional, norm-referenced, multiple-choice tests are criticized for not adequately measuring complex cognitive and performance abilities. Moreover, they have often been used to limit students' access to further learning opportunities (Darling-Hammond 1991, Glaser 1990, and Oakes 1985).

There are a variety of classroom, school and school district, state, and national tests used for numerous purposes. Their assessment functions include the following:

1. To make decisions about the performance of individual students and comparisons among students.
    - ♦ To determine the level or degree of attainment in a specific content area or in a body of content, as a diagnosis of individual strengths and weaknesses in a content area, and as a readiness indicator to determine if an individual has attained the requisite levels of understanding deemed necessary for continued study in a given content area (Bresica and Fortune 1988).
    - ♦ To make decisions about student promotion from grade to grade, placement in remedial or advanced level course tracks and for graduation from one educational level to the next (Madaus and Tan 1993).
2. To improve instruction and learning outcomes for students and to inform students, parents, and teachers about student, classroom, school, or district progress over time (Madaus and Tan 1993).
3. To hold educational systems accountable for performance, to make statewide decisions about the allocation of educational resources and interventions, and to assist policymakers and researchers in making evaluative judgments about the performance of existing educational programs and practices or the need for new ones (Madaus and Tan 1993).

The National Assessment of Educational Progress has been conducted in mathematics and science learning since the late 1960s and early 1970s. NAEP uses a formal, systematic procedure to obtain a sample of students' knowledge over time and to make generalizations about how student populations are performing. NAEP has attempted to add performance items to its assessment approach in order to assist in measuring not only students' knowledge of mathematics and science, but also their ability to apply that knowledge and to articulate various aspects of problem solving.

Numerous alternative assessment experiments are being implemented and debated in schools and communities across the nation. Different testing alternatives include performance tasks, open-ended questions, portfolios, observation, and student journal writing and self-assessment.

In recent years there has been a conceptual shift in some research and policy circles as to what constitutes "good" assessments of achievement. Some current trends in measuring and analyzing student performance include:

Notwithstanding the substantial cultural differences and variations in geographic settling patterns across these states and within the U.S. Hispanic population, it was most often in Southeastern states that Hispanic student achievement lagged farthest behind. The largest differences between averages for Hispanics and whites were found in Connecticut, New York, and four Southeastern states. (See appendix table 1-4 for science achievement scores for Asians/Pacific Islanders and Native Americans.)

U.S. Science Proficiency in an International Context

In the recent international comparative study on mathematics and science achievement (TIMSS), U.S. students performed better in science than in mathematics and better at the fourth grade than at the eighth grade level. U.S. fourth graders performed very well on the science assessment—they answered 66 percent of the science items correctly (compared with the international average of 59 percent). The only nation to score significantly higher was South Korea. (See figure

- greater emphasis on assessing higher order thinking skills and processes;
- comparing student performance with established standards;
- making the assessment process public, participatory, and dynamic and including students as active participants in the assessment process;
- ensuring that all students have the opportunity to achieve their potential;
- aligning assessment with curriculum and instruction and other policies and practices;
- making inferences and/or judgments based on multiple sources of evidence; and
- viewing assessment as continual and recursive.

Research findings suggest that achievement tests of any kind are not a good predictor of success. Many forms of bias affect performance on tests: the choice of items, responses deemed appropriate, and the content selected are the product of culturally and contextually determined judgments (García and Pearson in press, Gardner 1983, and Sternberg 1985).

The factors that influence test scores (e.g., opportunities to learn, poverty and social class, test motivation and testing skills, language ability, and educational experiences outside of the classroom) are well-documented. These factors sometimes occur jointly—sometimes at different times—in the test-taking process, making it impossible to track each systematically. As Oakes et al. (1990) point out, although individual effects can be identified for both race and social class, for example, it is the combination of the two—their multiplicative power—that needs to be examined and measured. But new forms of assessment do not themselves remedy these socioeconomic complexities.

Darling-Hammond (1994b) argues that changing test forms and formats without changing the ways in which assessments are used will not change the outcomes of education. The equitable use of performance assessments depends on both the designs of the tests themselves and how well the assessment practices are interwoven with the progress of school reform and the improvement of teaching.

However, an assessment that attempts to perform too many functions will inevitably do none well. Some functions must be passed over in favor of others, and it is at this point that the test development process can become roiled in miscommunication. It is vital to delineate appropriate roles—student diagnosis, curriculum planning, program evaluation, instructional improvement, accountability, and certification—for different assessments (Linn and Herman 1997). And importantly, whatever test is created must be credible in the eyes of the public.

In analyzing test results, their meaning must not be misunderstood. For example, the results of a test given at various grade levels should not be interpreted as if they were an assessment of the progress of the same students over time (i.e., longitudinal). The results of annual achievement data reflect a (cross-sectional) snapshot of progress at that given time. The tests administered as part of TIMSS provide rich information about the performance of U.S. students compared to those of other countries in mathematics and science, and provide connections for understanding performance within the context of curriculum and instruction at specific grade levels. However, TIMSS data are not longitudinal in nature, meaning that the same students are not being tested in the fourth grade and then, four years later, in the eighth.

Much more research is needed on the fairness and validity of new modes of assessment. In addition to these concerns, investigations into the effects of aligning assessments with rigorous standards for student achievement would benefit a multitude of local, state, and federal audiences. Nonetheless, it is not only the *form* of the tests that is important in determining the impact of an assessment program on students, teachers, and schools; it is the *use* to which the results are put (Messick 1989).

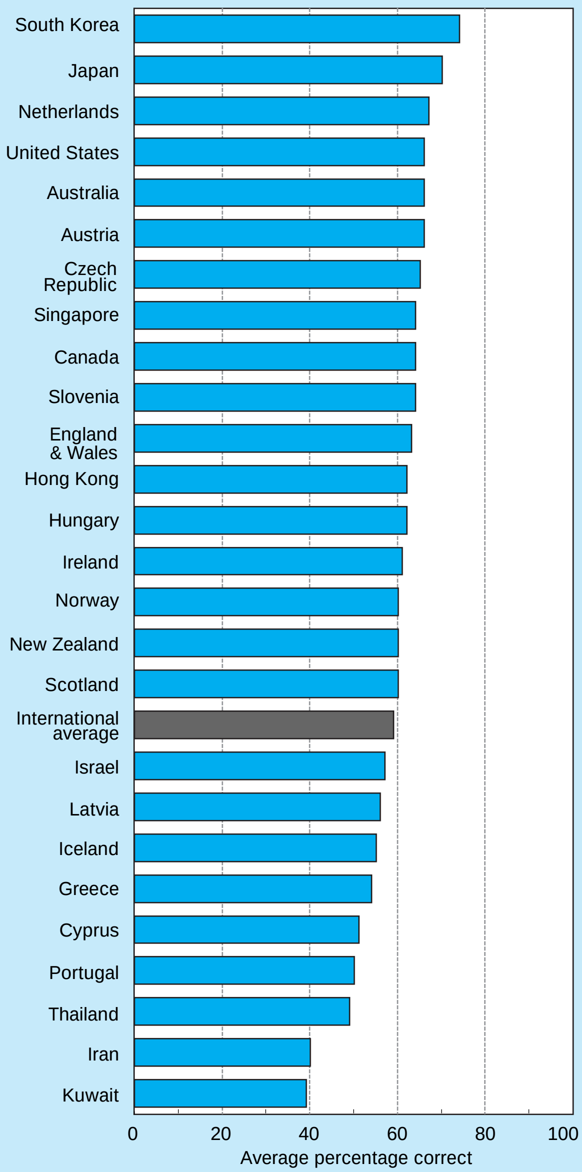
This discussion concentrates heavily on various concerns regarding the measurement of achievement at the elementary and secondary levels, where at least some actions have been taken to assess performance; this is in contrast to the postsecondary level, where gaps remain.

1-5.) In addition, U.S. fourth graders earned scores higher than the international average in all four science content areas: earth science, life science, physical science, and environmental issues/nature of science. (See appendix table 1-5.)

U.S. eighth grade students performed less well relative to other countries in science than fourth graders, scoring just above the international average. Eighth graders in the United States answered 58 percent of the science items correctly, compared with an international average of 56 percent. (See figure 1-6.) Like U.S. fourth graders, scores of U.S. eighth grade students exceeded the international average in all science content areas: earth science, life science, physics, chemistry, and environmental issues/nature of science. (See appendix table 1-6.)

In the United States, boys scored slightly higher than girls in science at the fourth grade, but there was no difference between the sexes at the eighth grade. In other countries that participated in the study, boys outperformed girls in science in 40 percent of the countries at the fourth grade and in almost half of the countries at the eighth grade. (See appendix table 1-7.)

Figure 1-5.
Average percentage correct on grade 4 TIMSS science assessment, by country: 1994-95



NOTE: TIMSS is the Third International Mathematics and Science Study.

See appendix table 1-5. *Science & Engineering Indicators – 1998*

Figure 1-6.
Average percentage correct on grade 8 TIMSS science assessment, by country: 1994-95

NOTE: TIMSS is the Third International Mathematics and Science Study.

See appendix table 1-6. *Science & Engineering Indicators – 1998*

Mathematics Coursework

U.S. students are now much more likely to have taken advanced mathematics courses in high school than they were in years past. In 1994, close to 70 percent of seniors had completed geometry, 58 percent had completed algebra 2, and 9 percent had completed calculus.[3] These figures represent a more than 20-point gain in the percentage of students taking

[3]Studies of high school transcripts may underestimate completion rates for algebra 1 (a prerequisite for geometry) because many college-bound students take algebra in eighth grade.

algebra 2 and geometry, and about a 5-point increase in calculus since 1982. High school females are now more likely than males to have taken geometry and algebra 2, and about as likely to have completed calculus. (See figure 1-7.)

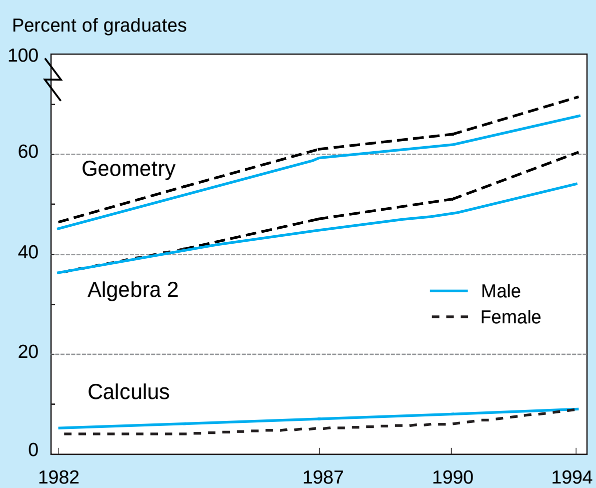
There remain substantial disparities across racial and ethnic groups in advanced mathematics coursetaking. This gap is apparent in geometry and algebra 2 as well as in the most advanced courses in the college preparatory sequence. In calculus, about one-quarter of Asian Americans/Pacific Islanders completed the course compared with about 10 percent of whites, 6 percent of Hispanics, and 4 percent each of blacks and Native Americans.

However, despite the unequal enrollments, progress has been made in the proportion of students in all racial and ethnic groups taking advanced mathematics. Half or more of white, Hispanic, and Asian American/Pacific Islander students in the class of 1994 completed algebra 2 and geometry, the so-called gatekeeper courses for advanced study in mathematics and science. Large gains were made in groups underrepresented in mathematics between 1982 and 1994. The proportion of black students taking geometry increased from 29 to 58 percent between 1982 and 1994. The proportion of Hispanics went from 26 to 69 percent, and the fraction of Native Americans taking geometry rose from 34 to 60 percent over the period. These groups also experienced 20 to 30 percentage point gains in algebra 2. (See figure 1-8.)

Mathematics Proficiency

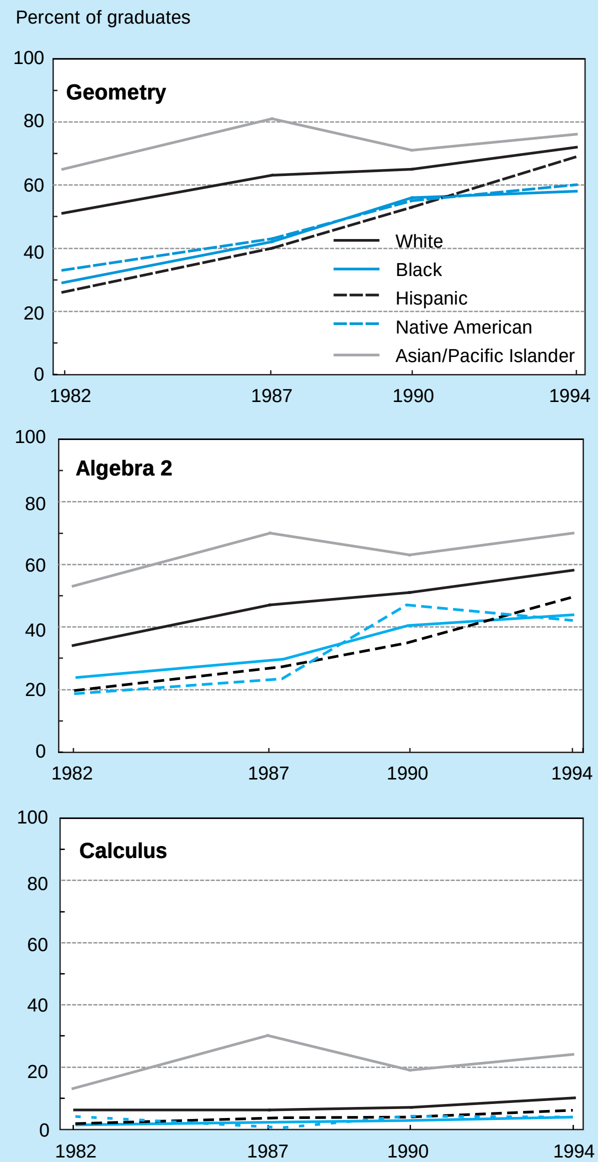
Mathematics performance of U.S. students remained fairly stable during the 1970s and began to improve in the 1980s. The most recent assessments indicate small but significant gains for 9-year-olds and 13-year-olds through 1996. (See

Figure 1-7.
Percentage of high school graduates earning credits in selected mathematics courses, by sex



See appendix table 1-8. *Science & Engineering Indicators – 1998*

Figure 1-8.
Percentage of high school graduates earning credits in mathematics courses, by race/ethnicity



See appendix table 1-9. *Science & Engineering Indicators – 1998*

figure 1-9.) On the other hand, performance of 17-year-olds remains at the 1973 level after recovering from a slight dip in the 1980s.[4]

Although the achievement of U.S. students in mathematics has shown slight gains over time, there remains a large proportion of students unable to demonstrate anything more than basic levels of knowledge (often associated with NAEP's level 2 performance). (See "The Making of a New Mathematics Assessment.") This is particularly true at grade 12 where just one in six students performed at or above level 3 (level 4 being the highest). At grades 4 and 8, respectively, approximately one in

[4]Detailed descriptions of trends can be found in Campbell et al. (1996).

The Making of a New Mathematics Assessment

National Assessment for Educational Progress tests in 1990, 1992, and 1996 differed markedly from earlier assessments in that they were designed to reflect the relatively new content and teaching standards published by the National Council of Teachers of Mathematics (NCTM 1989 and 1991). These newer assessments included questions from the five core content areas defined by the mathematics standards:

- number sense, properties, and operations;
- measurement;
- data analysis, statistics, and probability; and
- algebra and functions.

The 1990, 1992, and 1996 mathematics assessments also attempt to measure students' cognitive abilities such as those emphasized in the standards: reasoning, problem solving, and communicating with and about mathematics.

At the same time that standards-based assessments were being developed, efforts were made to associate numerical scores on the test with descriptive labels and definitions that capture the levels of knowledge and skill demonstrated by students' overall responses to test items. Results from the 1990 assessment placed performance on a continuum that ranged from knowledge of "simple arithmetic facts" at the low end to knowledge of "multistep problem solving and algebra" at the high end. Results from the 1992 and 1996 NAEPs were reported at one of four proficiency levels that ranged from "below basic" to "advanced." The value and validity of these proficiency levels have been matters of debate since their introduction (U.S. GAO 1993). To permit comparability with reported results without conveying judgments about the capabilities a particular score represents, this chapter reports performance levels simply designated as levels 1 to 4. These levels correspond numerically to the score ranges used in 1990 and 1992 mathematics assessment reports. (See appendix table 1-10.)

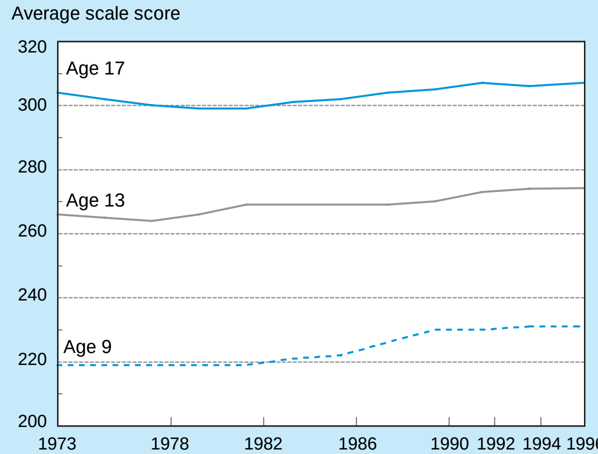
five and one in four students performed at this level. Despite the disappointing news, this is an improvement from 1990 when substantially fewer students demonstrated level 3 performance.

However, considerable progress has been made in the 1990s in the proportion of students performing at least at level 2. Between 62 and 69 percent—depending on grade level—of students in 1996 were able to perform the more basic levels of mathematics, compared with 52 to 58 percent in 1990. (See figure 1-10.)

In 1996, there were no substantial differences between the proportions of male and female students performing at or above level 2 in mathematics at any grade level. A slightly higher proportion of males than females demonstrated the more advanced performance (level 3) in 4th and 12th grades, but not in 8th grade. (See appendix table 1-10.)

As in science, differences in the mathematics achievement across racial and ethnic groups have followed a consistent pattern over the years: white and Asian American/Pacific Islander students generally achieve at significantly higher levels than

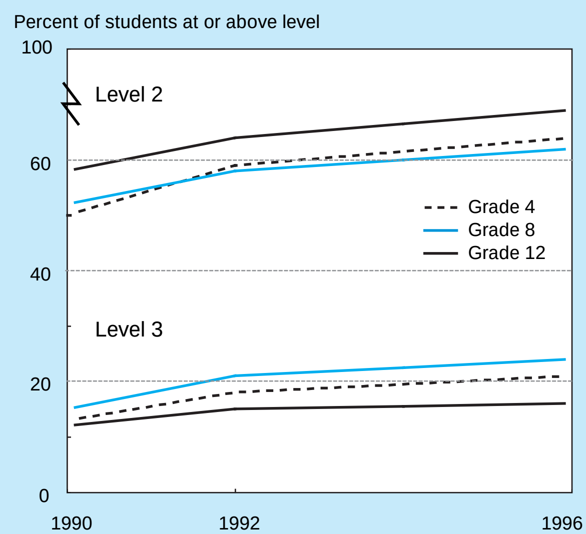
Figure 1-9.
National trends in average NAEP scale scores in mathematics at ages 9, 13, and 17



NOTE: NAEP is the National Assessment of Educational Progress.

See appendix table 1-27. *Science & Engineering Indicators – 1998*

Figure 1-10.
Percentage of students at or above levels 2 and 3 on NAEP mathematics assessments, by grade



NOTE: NAEP is the National Assessment of Educational Progress.

See appendix table 1-10. *Science & Engineering Indicators – 1998* do black, Hispanic, and Native American students. Despite some gains between 1990 and 1996, the proportion of black, Hispanic, and Native American students who performed at level 2 or above lagged far behind that of whites and Asian/Pacific Islanders. There were about 40 points between the percentage of white students at level 2 and the percentage of black students, about a 30-point lag for Hispanics, and about 20 points for Native Americans. (See appendix table 1-10.)

Larger proportions of white students in all three grades were performing at or above levels 2 and 3 at the end of the six-year period of the assessment than they were in 1990. The percentage of black fourth graders who performed at level 2 or above increased by 13 points between 1990 and 1996. Hispanic and Native American students showed no statistically significant improvement at any grade or at any level of proficiency during that period.

Also between 1990 and 1996, there has been a striking rise in the number of states where 50 percent or more of eighth grade students scored at or above level 2 mathematics proficiency.[5] In 1996, of the 40 states participating in the state-by-state analysis, only students in Alabama, Louisiana, Mississippi, and South Carolina failed to meet this performance criterion. In comparison, in 1992, only 23 of 35 states, and just half of 1990 participating states, could claim 50 percent or more of their students at or above level 2 performance. (See figure 1-11.) However, there were large differences among racial and ethnic groups across states in meeting the 50 percent criterion. In 1996, half or more of white eighth graders in all states achieved level 2 performance; only in Iowa, Montana, and North Dakota did half or more of Hispanic eighth grade students meet the basic level of proficiency; in no state did half or more of black students perform at this level.[6]

Studies suggest that state economic conditions play some part in mathematics achievement, although a direct and powerful relationship has not been identified. Four states in which less than half of eighth graders functioned at or above level 2 in mathematics (Alabama, Louisiana, Mississippi, and South Carolina) were compared with the six states in which three-quarters or more of students achieved at this level. Comparisons were based on three key variables: poverty rate, educational expenditure, and the percentage of minority students in each state. Comparisons suggest an association between these indicators and mathematics performance. (See text table 1-1.)

- ♦ In low-performing states, the poverty index ranged from 19 to 37 percent, and in high-performing states, from 10 to 14 percent.
- ♦ In low-performing states, average per student spending on education ranged from $3,660 in Mississippi to $4,761 in South Carolina; in high-performing states, the range was $4,674 in North Dakota to $6,069 in Maine.[7]
- ♦ All four of the low-performing states included much larger percentages of minority students (from 40 to 49 percent) than did high-performing states (from 9 to 17 percent).

[5]Because only eighth grade students participated in all three of these assessments, only their performance is considered in these comparisons.

[6]Because sample sizes for Native American and Asian/Pacific Islander students were too small in most states to provide reliable estimates of proficiency levels, these comparisons are not made here but can be found in appendix table 1-11.

U.S. Mathematics Proficiency in an International Context

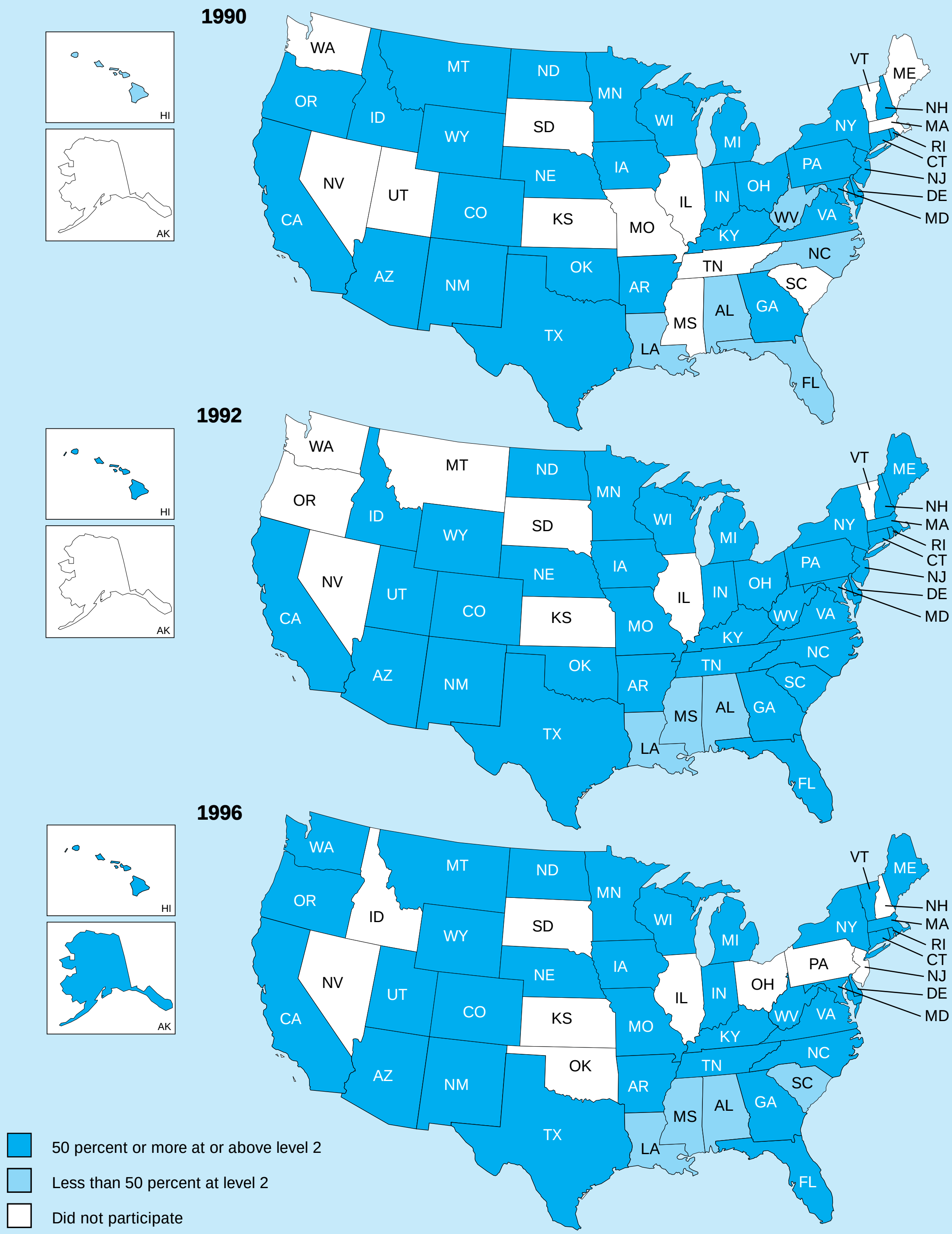
As in science, performance in mathematics of U.S. fourth grade students in the1995 TIMSS study was comparatively better than eighth grade performance, averaging 63 percent of items correctly answered compared with 59 percent internationally. (See figure 1-12.) But, unlike in science, U.S. mathematics performance at fourth grade was far behind that of Singapore, South Korea, Japan, and Hong Kong—whose fourth grade students averaged 73 to 76 percent correct—and a host of other countries. (See figure 1-13.) U.S. eighth graders answered just over half of the items on the mathematics assessment correctly. This was below the international average of 55 percent correct, and students in the highest performing nations—Singapore, South Korea, Japan, Hong Kong, and Flemish-speaking Belgium—averaged 65 percent correct or higher. In most countries—including the United States—there were no differences between the sexes in mathematics performance at the fourth or eighth grade. (See "Mathematics and Science Achievement of the Highest Performers" and appendix table 1-14.)

[7]These figures are not adjusted for differences in cost of living among states.

Mathematics and Science Achievement of the Highest Performers

Achievement can also be evaluated by comparing the top students in different nations. Often, the comparison is based on the proportion of each nation's students scoring in the top 10 percent of the international distribution. As would be expected on the basis of findings already presented, proportionately more students from Singapore, South Korea, and Japan came out on top in both subjects and at both the fourth and eighth grade levels. For example, at the eighth grade level, 45 percent of the students from Singapore scored in the top 10 percent of the international mathematics distribution and 31 percent scored at the top of the science distribution. A smaller percentage of U.S. students made the top cut. In science, 13 percent of eighth grade students and 16 percent of fourth grade students scored in the top 10 percent of their respective international distributions. In mathematics, only 5 percent of U.S. students in eighth grade and 9 percent of students in fourth grade reached the top 10 percent international benchmark. (See appendix table 1-15.)

Figure 1-11.
NAEP grade 8 average scale scores in mathematics, by state



NOTE: NAEP is the National Assessment of Educational Progress.

See appendix table 1-11.

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Text table 1-1.
Selected characteristics of low- and high-performing states on the mathematics National Assessment of Educational Progress: 1996

State	Percentage of students at or above level 2	Percentage of 5- to 17-year-olds in poverty	Per pupil educational expenditures ($)	Percentage of minority students
National total	61	20.1	5,767	31
Low-performing states				
Alabama	45	19.5	4,037	40
Louisiana	38	36.8	4,519	45
Mississippi	36	28.2	3,660	51
South Carolina	48	18.7	4,761	49
High-performing states				
Iowa	78	13.5	5,288	9
Maine	77	9.6	6,069	7
Minnesota	75	13.7	5,720	14
Montana	75	12.3	5,598	17
Nebraska	76	12.5	5,651	15
North Dakota	77	11.6	4,674	9

SOURCES: C. O'Sullivan, C. Reese, and J. Mazzeo, *NAEP 1996 Science Report Card for the Nation and the States* (Washington, DC: National Center for Education Statistics, 1997); C. Reese, K. Miller, J. Mazzeo, and J. Dossey, *NAEP 1996 Mathematics Report Card for the Nation and the States* (Washington, DC: National Center for Education Statistics, 1997); and National Center for Education Statistics, *Digest of Educational Statistics 1996*, NCES 96-133, (Washington, DC: U.S. Government Printing Office, 1996), table 165.

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The performance of students varied over mathematics content areas both within and among countries.[8] In fourth grade mathematics, U.S. students performed at or above the international average in all areas except measurement. (See appendix table 1-12.) U.S. eighth grade students performed best on algebra, fractions, and data representation/analysis, where performance was on a par with international averages. They did less well on proportionality, geometry, and measurement. (See appendix table 1-13.)

Curriculum and Instruction

When student assessments reveal differences in performance across nations or states or within population groups of the magnitude that they have displayed in the assessments analyzed here, there is a compelling policy need to explore the sources of these disparities. A better understanding of why some groups of students perform well in mathematics and science while others do not can help educators and policymakers in deciding which facets of the education system require more or less attention.

Many recent analyses have focused on differences in the educational experiences of students. The Third International Mathematics and Science Study provides more comprehensive information on the educational experiences of students than any international (and many national) studies conducted to date. Within this large-scale study, a curriculum analysis provides country profiles of the mathematics and science that students are expected to learn at each grade.[9] Student and teacher surveys provide information on the subject matter content and activities that make up a lesson; and a video study (for the United States, Germany, and Japan) provides observational information on what actually takes place in a sample of eighth grade mathematics classrooms.

Mathematics Curricula

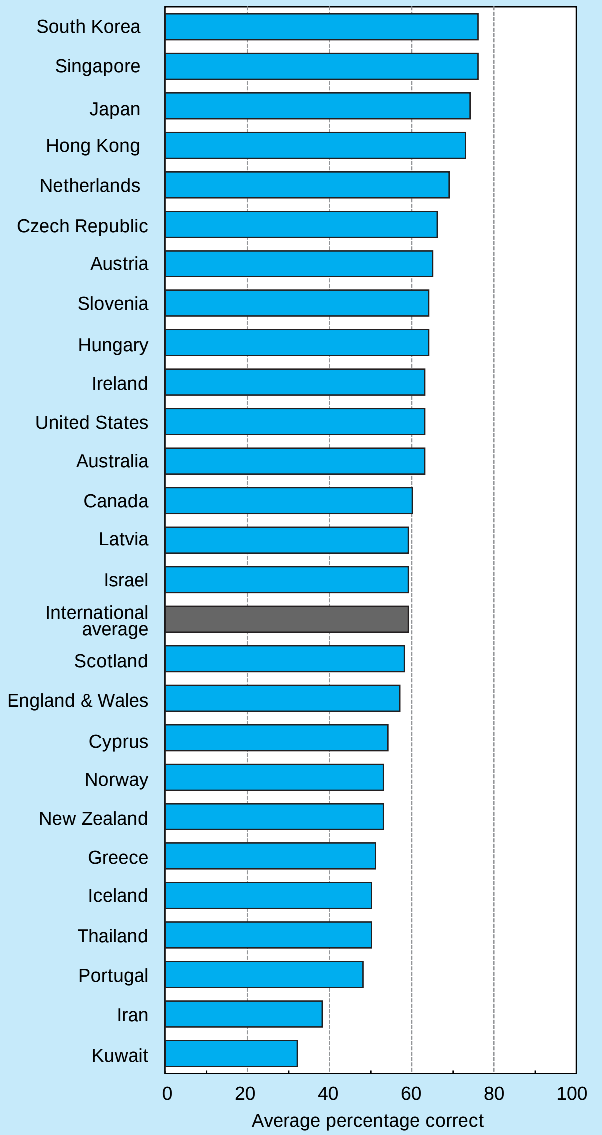
In most countries, curricula focus on a limited number of topics at each grade. Each topic is introduced in the grade sequence and continues until a point when it is discontinued in favor of a new topic. In contrast, U.S. curricula follow a spiral approach: a topic is introduced in its simplest terms in early grades and continues in more advanced forms into later grades. Topics thus "spiral" throughout the curriculum—in theory, providing greater depth, elaboration, and complexity at each appearance. Three central ideas underlie the U.S. approach. First, content is more easily mastered when broken into "bite-sized" pieces. Second, the pieces are best learned when presented in order of difficulty and complexity. Third, students must master each piece before moving on to the next.

However, this approach when put into actual practice has important consequences for learning and instruction that are not always consistent with the theory. The U.S. curricula include a great deal of repetition over grades, and despite the intent to present new aspects of a topic at each appearance,

[8]Items and topics in the assessment were grade-specific. For example, the fourth grade test focused on whole numbers with a limited number of questions on fractions. The eighth grade test focused on rational numbers (fractions and decimals)

[9]Details of the curriculum study's methodology and findings are presented in Schmidt, McKnight, and Raizen (1997) and in two companion volumes (Schmidt, McKnight et al. 1997 and Schmidt, Raizen et al. 1997)—one for science and one for mathematics—written by these and other members of the TIMSS research team.

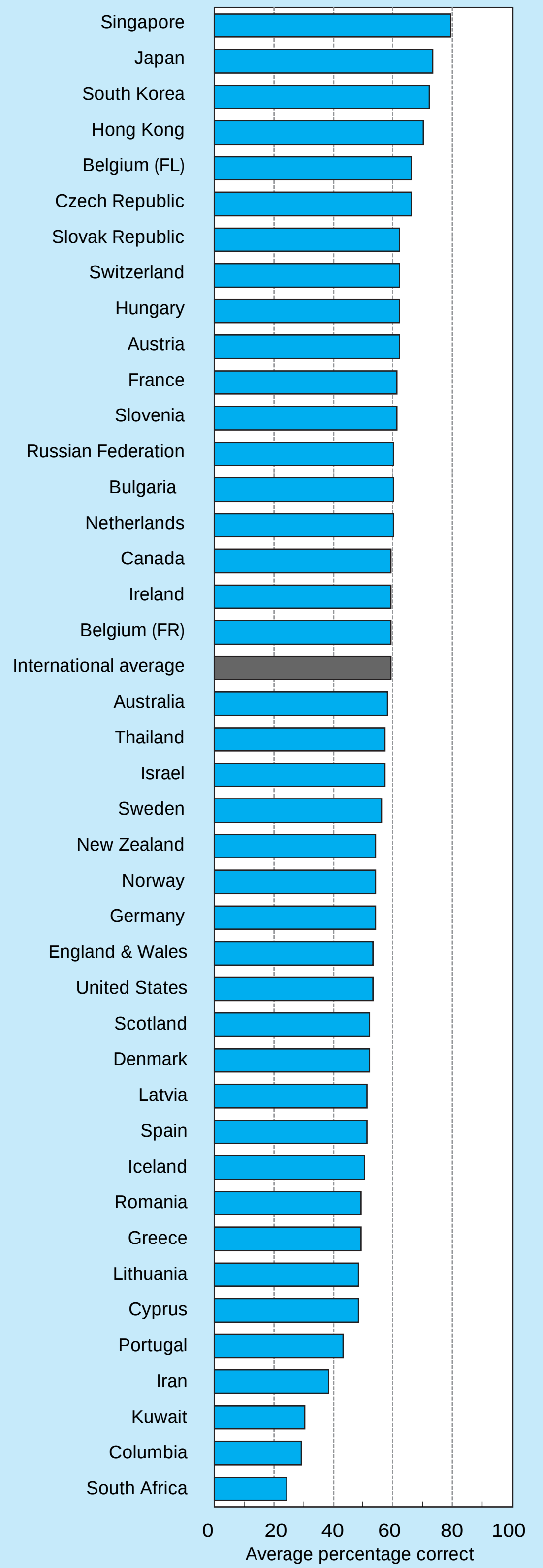
Figure 1-12.
Average percentage correct on grade 4 TIMSS mathematics assessment, by country: 1994-95



NOTE: TIMSS is the Third International Mathematics and Science Study.

See appendix table 1-12. *Science & Engineering Indicators – 1998*

Figure 1-13.
Average percentage correct on grade 8 TIMSS mathematics assessment, by country: 1994-95



NOTE: TIMSS is the Third International Mathematics and Science Study.

See appendix table 1-13. *Science & Engineering Indicators – 1998*

much of the information seems to get rehashed from previous levels. On average, topics remain in the mathematics curriculum as a whole two years longer than is the norm internationally. And the curriculum includes a large number of topics since few are dropped as others are added. On average, the U.S. mathematics curriculum covers more topics than are covered in 75 percent of countries that participated in the 1995 international study.

Analyses of topics covered at various grade levels in mathematics textbooks across the world illustrate this point. At fourth grade, the five most emphasized mathematics topics accounted for 60 percent of page space in U.S. textbooks but over 85 percent internationally. In eighth grade mathematics, the five most emphasized topics in U.S. (nonalgebra) texts accounted for less than 50 percent of total coverage, compared with 75 percent internationally.[10] U.S. eighth grade textbooks for regular, nonalgebraic mathematics cover approximately 36 different topics, compared with an average of 8 topics in Japanese and 4.5 topics in German texts.[11] Findings are similar for the 4th and 12th grades. (See figure 1-14.)

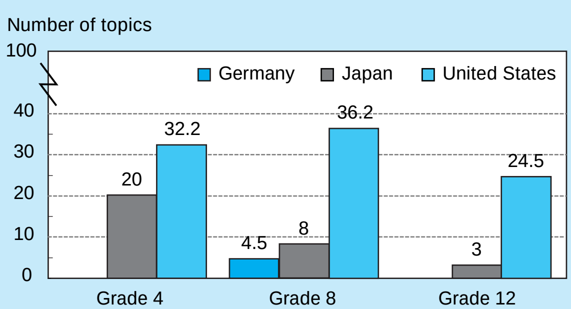
A review of the topics emphasized at each grade level reveals that U.S. mathematics texts are also often out of step with the international norm. For example, at eighth grade—where U.S. students perform relatively poorly in mathematics compared with other nations—the international norm is to focus on algebra and geometry. In the United States, eighth grade texts place greater emphasis on whole numbers, decimals, and fractions—topics that most other countries have already completed. Videotaped lessons confirm this finding. Lessons in German and Japanese classrooms were focused on algebra and geometry, while, in about 40 percent of the cases, U.S. lessons focused on arithmetic (NCES 1996c).[12]

[10]The five most emphasized topics in eighth grade algebra texts in the United States accounted for 100 percent of textbook space.

[11]Results of the curriculum analysis for German texts are reported only for eighth grade.

[12]Key findings from the video summary are presented in NCES (1996c). Details of the methodology, coding schemes, and findings have been presented in a recently issued volume prepared by James Stigler and colleagues at UCLA (Stigler et al. 1997).

Figure 1-14.
Average number of topics in mathematics textbooks in Germany, Japan, and the United States, by grade: 1994-95



NOTE: Data are from the Third International Mathematics and Science Study. Eighth grade algebra texts not included.

SOURCE: W.H. Schmidt, C.C. McKnight, and S.A.Raizen, *A Splintered Vision: An Investigation of U.S. Science and Mathematics Education* (Boston: Kluwer Academic Publishers, 1997).

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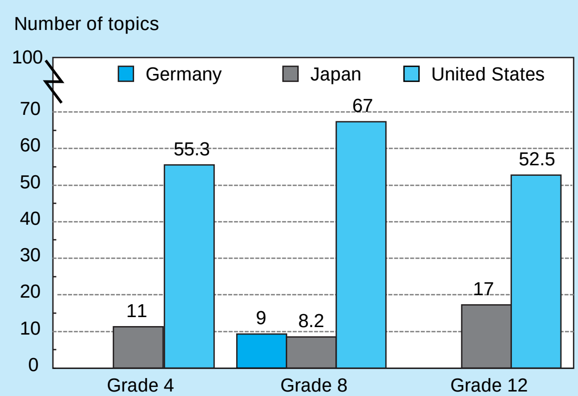
Science Curricula

Overall, the U.S. science curriculum has more in common with the curricula of other countries than is the case for U.S. mathematics. Still, U.S. science curricula reflect some of the patterns observed in mathematics. In the United States, new topics are introduced at regular intervals in the first five grades. Much of the content seems repetitive until about 10th grade, when general science is replaced by courses devoted to specific areas of science such as biology, chemistry, or physics.

However, in the elementary and middle grades, U.S. students take general science courses that cover more topics than are covered in most of the participating countries. General science textbooks in the United States tend toward inclusiveness, covering more distinct topics than are covered in texts in 75 percent of the other countries. The typical U.S. science textbook covers between 53 and 67 topics, depending on grade level. In Japan, the range is 8 to 17 topics. In Germany, where data were available only for eighth grade, the average is nine topics. (See figure 1-15.)

This tendency toward inclusive coverage means that most general science textbooks in the United States touch on topics rather than concentrating on them. As an example, the five most emphasized topics in U.S. fourth grade science texts accounted for 25 percent of the total textbook space, compared with an international average of 70 to 75 percent. In eighth grade, the five most emphasized topics in U.S. general science texts accounted for 50 percent of textbook space, compared with 60 percent internationally.

Figure 1-15.
Average number of topics in general science textbooks in Germany, Japan, and the United States, by grade: 1994-95



NOTE: Data are from the Third International Mathematics and Science Study.

SOURCE: W.H. Schmidt, C.C. McKnight, and S.A. Raizen, *A Splintered Vision: An Investigation of U.S. Science and Mathematics Education* (Boston: Kluwer Academic Publishers, 1997).

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Instructional Practice and Quality

Textbooks and curriculum guides are not the only critical factors in curriculum and instruction. Equally critical from the perspective of educational reformers are instructional considerations such as the amount of time students spend engaged with subject matter, the kinds of tasks used to facilitate their problem-solving and thinking capacities, and the technological tools available to support active student learning.

Differences in student performance outcomes are determined, at least to some degree, by differences in instructional practice and instructional quality. Science instruction in the United States may be roughly comparable to science instruction in other countries. But, as revealed in the recent international comparison, eighth grade mathematics classes in the United States are pitched at a lower level than in higher achieving countries. While U.S. eighth graders are still working on “high-end arithmetic,” their peers in other countries are learning algebra and geometry.

The international comparison also revealed differences in goals, activities, and overall lesson quality in the United States, Germany, and Japan. The goal of mathematics lessons in the United States and Germany was most often to have students learn a particular skill, while the goal in Japanese classrooms was more often to help students develop deep understandings of mathematics (see NCES 1997c). These differences in goals translated into differences in other aspects of instruction. For example, 71 percent of Japanese teachers provide learning activities that require high-level thinking and reasoning. In comparison, only 29 percent of German teachers and 24 percent of U.S. teachers engaged students in this kind of learning (NCES 1997c).

On the basis of a videotaped sample of eighth grade mathematics classrooms in the three countries, judges rated most lessons from U.S. classrooms to be of low quality (87 percent), compared with 40 percent of lessons from German classrooms and just 13 percent of Japanese lessons. These judgments were made independently of detailed summaries that documented the exact sequence of mathematical statements and equations presented and the learning activities used. Any words that provided clues to the identity of the country were disguised.

None of the lessons from U.S. mathematics classrooms were rated high on quality, compared with 30 percent of lessons from Japanese classrooms and 23 percent from German classrooms. Moreover, most of the expert judges viewed lessons in Japanese classrooms as more consistent with U.S. mathematics standards than lessons in U.S. classrooms. However, 75 percent of the U.S. teachers of those same lessons judged their own instruction to be in “some accord” with the standards.

Time on Learning

Aside from the issue of instructional quality, there has been some empirical evidence to support the common-sense notion that the more time students spend engaged in learning, the more they will learn. This is the primary reason why time is considered an important instructional variable. It is considered so crucial, in fact, that many educators believe systemic change cannot be successful in schools unless ways are found to provide students with more learning time (National Education Commission on Time and Learning 1994). Still, questions remain about just how much influence instructional time has on achievement.

Through the recent international comparative study, it has become clear that, at the very least, the relationship is not as simple as has been assumed. In fact, no consistent relationship was observed between class time and achievement in either subject at either fourth or eighth grade.[13] This finding suggests that how teachers and students spend their instructional time is more important than the amount of time available for mathematics and science instruction during the school day. For example, eighth grade students in Belgium, the Czech Republic, and the Slovak Republic—all high-performing nations—reported spending more time than the average on mathematics. But so too did students in Kuwait, who were among the lowest scorers. South Korean and Japanese eighth graders reported spending the international average amount of class time on mathematics but were among the highest achievers.

U.S. students spend at least as much class time on mathematics and science as students in most countries. At eighth grade, over half of U.S. students spend 3½ to 5 classroom hours on mathematics each week compared with an international norm of 2 to 3½ hours (Beaton, Mullis et al. 1996; and Beaton, Martin et al. 1996).[14] Almost half of fourth grade U.S. students spend five or more hours of instructional time each week on mathematics and three hours or more on science. In most other countries, fourth graders spend about three to four hours on mathematics and two hours on science (see Martin et al. 1997 and Mullis et al. 1997).[15]

Although learning time can be extended through homework and study before or after the school day, no consistent relationship has been found between international achievement and the amount of time students reported spending on homework. In some high-achieving countries such as Hungary, Singapore, and Slovenia, students spend considerably more time than the norm on homework. However, students in low-achieving countries such as Iran and Kuwait also reported considerable time on homework. In Denmark, Scotland, and the Netherlands—which are middle- to high-achieving countries—one-quarter to one-half of the students reported spending no time at all on homework on a normal day.[16]

Students in most countries reported spending an hour of nonschool time on mathematics on a normal day and a half-

[13]See table 4.9 in each of the following sources: Beaton, Mullis et al. 1996; Beaton, Martin et al. 1996; Martin et al. 1997; and Mullis et al. 1997.

[14]See Beaton, Mullis et al. (1996, table 5.5). Comparable figures are not available for eighth grade science classes in the United States.

[15]For mathematics, see Mullis et al. (1997, table 5.4); for science, see Martin et al. (1997, table 5.5).

[16]See table 4.9 of Beaton, Mullis et al. (1996); and Beaton, Martin et al. (1996).

hour to an hour on science. U.S. students averaged 48 minutes to one hour on mathematics homework and between 36 and 48 minutes on science, depending on grade level (Beaton, Mullis et al. 1996; Beaton, Martin et al. 1996; Martin et al. 1996; and Mullis et al. 1996).[17] (See appendix table 1-17.)

Homework competes with extracurricular activities for students' attention, and television often turns out to be the prime competitor. In most countries, eighth grade students spend two to three hours a day watching television. (See figure 1-16) The habit of U.S. students are consistent with these patterns: eighth graders reported spending 2.6 hours watching television, compared with 2.3 hours doing their school homework or studying. Not only was this within the international norm, but it was virtually identical to patterns exhibited by Japan and Hong Kong, two of the top-scoring economies. Students in other high-scoring countries such as Singapore and Belgium spent somewhat more time studying than watching television; however, students in the Czech Republic spent more time watching television than studying.

The relationship of achievement to time spent viewing television is more consistent than the relationship between achievement and time spent on homework—but it turns out to be a curvilinear relationship. Students who watched one to two hours of television were the highest achievers in most countries. Students who watched more than two hours of television or less than one hour had lower mathematics and science achievement on average. More significant perhaps was the finding that eighth grade students who watched television for five or more hours each day, and fourth grade students who watched TV for four or more hours, were the lowest achievers in all participating countries. The United States had a fair number of students who spent this much time watching television—17 percent of fourth grade students and 13 percent of eighth grade students (Beaton, Mullis et al. 1996; Beaton, Martin et al. 1996; Martin et al. 1997; and Mullis et al. 1997).

Use of Instructional Technologies

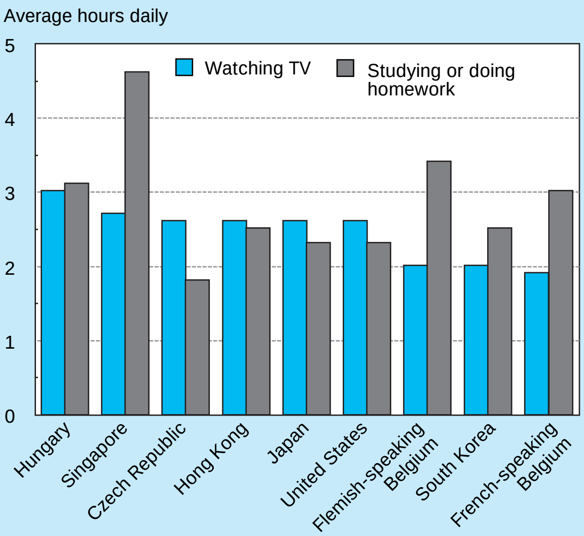
Educational standards in both mathematics and science acknowledge the potential benefits of technology and recommend that students have regular access to computers and other tools such as calculators. Although there are studies of individual schools or districts where the use of computers and access to the Internet have yielded learning gains, there are no national data that affirm that the presence of technology in itself is spurring achievement gains in mathematics and science nationwide. It is probably often the case that information technologies, when available, are not being used effectively in the classroom; nor does it seem from empirical analysis that educators have yet understood how to integrate technology into programs of reform on a wide scale.

By 1994, more than half of U.S. middle and high school students reported access to computers in school for mathematics instruction; of that number, about 62 to 70 percent actually used the computers to solve mathematics problems. This represents a large increase from 1978 when only 56 percent of 13-year-olds and 46 percent of 17-year-olds used computers for problem solving during instruction. (See text table 1-2.)

Teacher responses from recent international comparisons paint a slightly more limited picture of computer use for mathematics

[17]Beaton, Mullis et al. (1996, table 4.6). Also see table 4.9 of Beaton, Mullis et al. (1996); Beaton, Martin et al. (1996); Martin et al. (1997); and Mullis et al. (1997) for frequency if distribution of homework/study time.

Figure 1-16.
Average hours spent on homework and in watching TV, by eighth graders: 1994-95



See appendix table 1-17. *Science & Engineering Indicators – 1998*

Text table 1-2.
Percentage of students reporting school access to computers for mathematics instruction and learning

Computer access/use	Year	13-year-olds reporting yes	17-year-olds reporting yes
Had access to computer to learn	1978	12	24
	1994	48	52*
Studied through computer instruction	1978	14	12
	1994	50*	34*
Used a computer to solve problems	1978	56	46
	1994	70*	62*

* = statistically significant difference between the two years, at a 5 percent combined significance level per set of comparisons

SOURCE: J. Campbell, C. Reese, C. O'Sullivan, and J. Dossey, *NAEP 1994: Trends in Academic Progress* (Washington, DC: National Center for Education Statistics, 1996).

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instruction. When asked about the use of computers in mathematics instruction, three-quarters of U.S. teachers at the eighth grade level reported that students never or hardly ever solve mathematics problems using a computer. Sixty percent of U.S. fourth grade teachers reported that students never or hardly ever use the computers in solving mathematics problems.[18] However, mathematics teachers reported frequent instructional use of calculators. More than half of eighth grade mathematics teachers in the United States reported that students in their classes use calculators for basic tasks such as checking answers and performing routine computations. More than half also reported having their students use calculators to solve complex problems and more than one-third to explore number concepts (Williams et al. 1997). (See appendix table 1-23.)

Across the world, computers are used quite rarely for mathematics and science instruction. Except in Denmark, England and Wales, and Slovenia, less than one-fifth of eighth grade students used computers for problem solving in science. And except in the United States, Austria, Denmark, England and Wales, and Sweden, less than one-third of fourth grade students used computers at least some of the time according to teachers' reports. (See appendix table 1-16.)

[18]U.S. data on computer use are reported only for mathematics classes. Fourth grade teachers were not asked about computer use in science. The response rate for eighth grade science teachers in the United States was too low for estimates to be reliable.

Limited availability of computers at school can be offset by access to computers at home, even though home computers are often used for other than academic purposes. During the 1994/95 school year, about half of U.S. students had a computer at home. Students in England and Wales, Iceland, Ireland, the Netherlands, and Scotland were most likely to own computers (about 75 percent); students in Colombia, Iran, Latvia, Romania, and Thailand were least likely (less than 20 percent). (See text table 1-3.)

The vision of tomorrow's classroom held by many educational reformers not only includes access to computers by students and teachers but also widespread access to the Internet. Although most U.S. schools are quite far from this vision, Internet access in schools has increased substantially in the last several years. A recent survey indicated that in fall 1996, 65 percent of public schools reported access to the Internet—a gain of 30 percentage points over 1994 figures. Internet access was more likely in secondary than in elementary schools (three-quarters versus under two-thirds); in more affluent than less affluent schools (78 percent versus 53 to 58 percent); and in schools with low to moderate minority enrollments, as compared with schools with high minority enrollments (65 to 72 percent versus 56 percent). (See appendix table 1-25.) As with computers, access to the Internet does not always translate into use by students and teachers, nor does it ensure effective use. Although close to two-thirds of U.S. schools could connect to the Internet, access was pos-

Text table 1-3.
Percentage of students reporting that they have a computer at home, by country: 1994-95

Country	Grade 4	Grade 8	Country	Grade 4	Grade 8
Australia	63	73	Kuwait	66	53
Austria	61	59	Latvia	21	13
Belgium (Flemish-speaking)	–	67	Lithuania	–	42
Belgium (French-speaking)	–	60	Netherlands	80	85
Canada	52	61	New Zealand	53	60
Colombia	–	11	Norway	56	64
Cyprus	35	39	Portugal	34	39
Czech Republic	33	36	Romania	–	19
Denmark	–	76	Russia	–	35
England and Wales	88	89	Scotland	89	90
France	–	50	Singapore	44	49
Germany	–	71	Slovak Republic	–	31
Greece	23	29	Slovenia	43	47
Hong Kong	37	39	South Korea	23	39
Hungary	37	37	Spain	–	42
Iceland	81	77	Sweden	–	60
Iran	8	4	Switzerland	–	66
Ireland	79	78	Thailand	3	4
Israel	70	76	United States	56	59

– = did not participate in fourth grade assessment

SOURCES: A. Beaton, I. Mullis, M. Martin, E. Gonzalez, D. Kelly, and T. Smith, *Mathematics Achievement in the Middle School Years: IEA's Third International Mathematics and Science Study (TIMSS)* (Chestnut Hill, MA: Boston College, 1996); and I. Mullis, M. Martin, A. Beaton, E. Gonzalez, D. Kelly, and T. Smith, *Mathematics Achievement in the Primary School Years: IEA's Third International Mathematics and Science Study* (*TIMSS*) (Chestnut Hill, MA: Boston College, 1997).

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sible from only 14 percent of instructional rooms (e.g., classrooms, computer labs, library media centers) according to recent surveys (NCES 1997a). (See figure 1-17.)

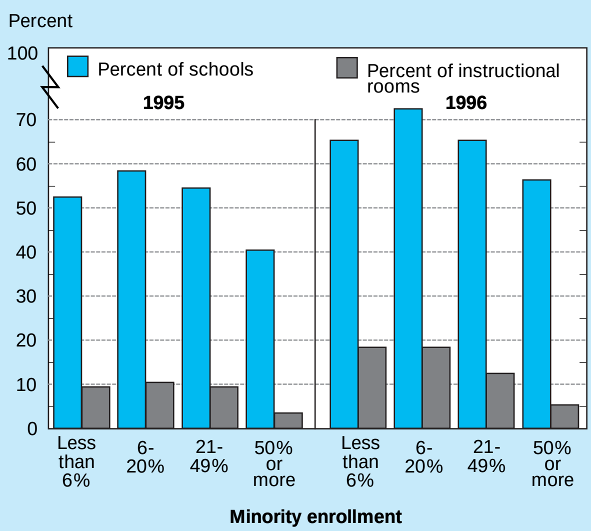
Teachers and the Profession of Teaching

The National Council of Teachers of Mathematics' standards and the National Research Council's science standards present new visions of what should be taught, as well as when and how it should be taught. Standards in both subjects call for teachers to introduce and develop topics that, in the past, were reserved for later grades and to orchestrate instruction in ways that are not commonly observed in today's classrooms. At present, few teachers possess both the knowledge of teaching and learning and the knowledge of content necessary to meet these expectations for the effective teaching of mathematics and science.

Teacher Preparation and Student Achievement

Until recently, attempts to link student achievement to teacher qualifications focused on degrees earned and major or minor fields of study. These attempts have not been altogether successful; few, if any, consistent effects were found. This was a sensible research strategy at the time because teacher certification requirements were specified in those terms. But more contemporary findings suggest that additional coursework in specific areas may not only increase teachers' knowledge of subject matter, but may also expand the range of teaching and learning approaches a teacher is likely to use in the classroom—and expand student achievement.

Figure 1-17.
Percentage of U.S. public schools and instructional rooms with Internet access, by proportion of minority enrollment



See appendix table 1-25.

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Recent studies are using more refined ways to measure teacher qualifications and, as a result, have established that the number and kind of courses taken by mathematics and science teachers do influence student performance. Higher student test scores have been related to teachers who have had more advanced courses in mathematics and science and in other educational areas. Taking additional coursework in unrelated subjects had no—or sometimes even a negative—effect on student learning (Monk 1994).

In addition, students whose teachers have completed more course credits in their field (and those with higher grade point averages) achieve at higher levels than other students. In a study conducted by Chaney (1995), teachers who had taken courses in mathematics at above calculus level coupled with courses in mathematics education were found to have students who less frequently scored in the lower achievement grouping and more often demonstrated advanced levels of performance. (See appendix table 1-26.) In addition, these better prepared teachers were more likely to expose their lower level mathematics students to college preparatory subjects such as algebra in regular mathematics classes (Chaney 1995).

Still other studies examining the knowledge base and preparation of teachers have identified important differences in instruction. Several of these studies showed that when covering topics on which they were well-prepared, teachers more often encouraged student questions and discussion; spent less time on unrelated topics; permitted discussion to move in new directions on the basis of student interests; and generally presented the topics in a more coherent, organized fashion. When covering unfamiliar topics, teachers discouraged active participation by students, kept discussion under tight rein, relied more on presentations than on student discourse, and spent more time on tangential issues such as study skills and cooperative effort (see, e.g., Carlsen 1991, and Smith and Neale 1991).

Coursework Preparation

An increasing number of states are requiring that teachers have a college major or a minimum number of credits in the subjects they plan to teach. Twenty-nine states now require, at least at the middle and high school levels, that teachers have a degree in a specific subject area other than education. Nine of these states also require this of elementary school teachers (CCSSO 1996). (See appendix table 1-20.)

As of the 1993/94 school year, 1 percent of elementary school teachers possessed a mathematics degree, 2 percent had a science degree, and only 5 or 6 percent more had either majored or minored in mathematics or science education in college. The vast majority of elementary school teachers earn college degrees in education rather than in specific disciplines or disciplinary areas of education. High school teachers were much more likely to possess mathematics and science degrees. Of high school mathematics teachers, 41 percent had earned a degree in mathematics compared with just 7 percent of middle school teachers. In science, 63 percent of high school, and 17 percent of middle school, science teachers possessed some form of science degree. (See text table 1-4.)

The professional associations have made specific recommendations for the preparation of mathematics and science teachers. (See “Are Teachers Knowledgeable About the Standards?”) The NCTM standards recommend that middle school mathematics teachers take college courses in abstract algebra, geometry, calculus, probability and statistics, and applications of mathematics/problem solving. An even more detailed list of coursework is recommended for high school mathematics teachers (Weiss, Matti, and Smith 1994).

Many middle school mathematics teachers fall short of these recommendations. Only 7 percent of middle school mathematics teachers have taken courses in all of the areas recommended by the standards, and about one-third have taken none. High school teachers are generally better prepared. About one-third have completed courses in at least 9 of 10 recommended areas, and only 2 percent have completed just one course or none of the recommended coursework. Virtually all elementary school teachers have completed some courses in mathematics education or mathematics for elementary teachers: 42 percent have completed college algebra/trigonometry, or elementary functions, but only 12 percent have completed calculus (Weiss, Matti, and Smith 1994).

The National Science Teachers Association recommends that elementary school teachers have one course each in the biological, physical, and earth sciences as well as coursework in science education. Just about half of elementary teachers have satisfied this requirement. Middle school science teachers are encouraged to take at least two courses in each area as well as teacher training in their field (Weiss, Matti, and Smith 1994). Only 42 percent of middle school science teachers (grades 5 to 8) and 57 percent of junior high school (grades 7 to 9) science teachers meet the Association’s recommendations in full. Recommended courses for the prospective high school teacher are quite detailed in each of the three areas of science, and there is a considerable range in the number of teachers meeting those recommendations. Less than half of earth science teachers, compared with 90 percent of biology teachers, had taken six or more credits in their respective subject areas (Weiss, Matti, and Smith 1994).

Teachers’ Views of Teaching and Learning

How teachers go about their work in classrooms depends to some extent on their views about the nature of their academic disciplines and about teaching and learning in their fields. Research in the last 10 years supports this claim (Dwyer 1993a and 1993b). Teachers who see science as a static collection of facts tend toward instructional approaches that rely on “teacher-talk” and direction, and on student practice and memorization. Teachers who see science as a process of empirical discovery are more comfortable with hands-on learning and open-ended tasks (Carlsen 1991, and Smith and Neale 1991). Others have made similar observations about the views and practices of mathematics teachers (Dossey 1992 and Thompson 1992).

The majority of teachers have fairly practical views of mathematics and science. Close to 80 percent of teachers in both subjects see their fields as providing “formal ways of representing the real world,” and close to 90 percent as a “structured guide for addressing real situations.” Only 31 percent of mathematics teachers and 18 percent of science teachers view their subject as an abstract conceptual system.

A number of teachers have views that run counter to the general directions set by standards. Close to 80 percent of mathematics teachers believe that some students have a natural talent for mathematics while others do not, and 35 percent think that mathematics should be learned as a set of algorithms or rules. In science, teachers sometimes hold similar views. Almost two-thirds of science teachers believe that some students have a natural talent for science and others do not. About three-quarters believe that students should be given prescriptive and sequential directions for doing experiments;

Text table 1-4.
Percentage of teachers with majors and minors in science/mathematics and science/mathematics education: 1993

Major/minor	Science teachers			Mathematics teachers		
	Grades 1-4	Grades 5-8	Grades 9-12	Grades 1-4	Grades 5-8	Grades 9-12
Undergraduate major in science/mathematics	2	17	63	1	7	41
Undergraduate or graduate major in science/science education or mathematics/mathematics education	3	21	72	1	11	63
Undergraduate or graduate major or minor in science/science education or mathematics/mathematics education	7	32	94	7	18	81

SOURCE: I.R. Weiss, M.C. Matti, and P.S. Smith, *Report of the 1993 National Survey of Science and Mathematics Education* (Chapel Hill, NC: Horizon Research, Inc., 1994).

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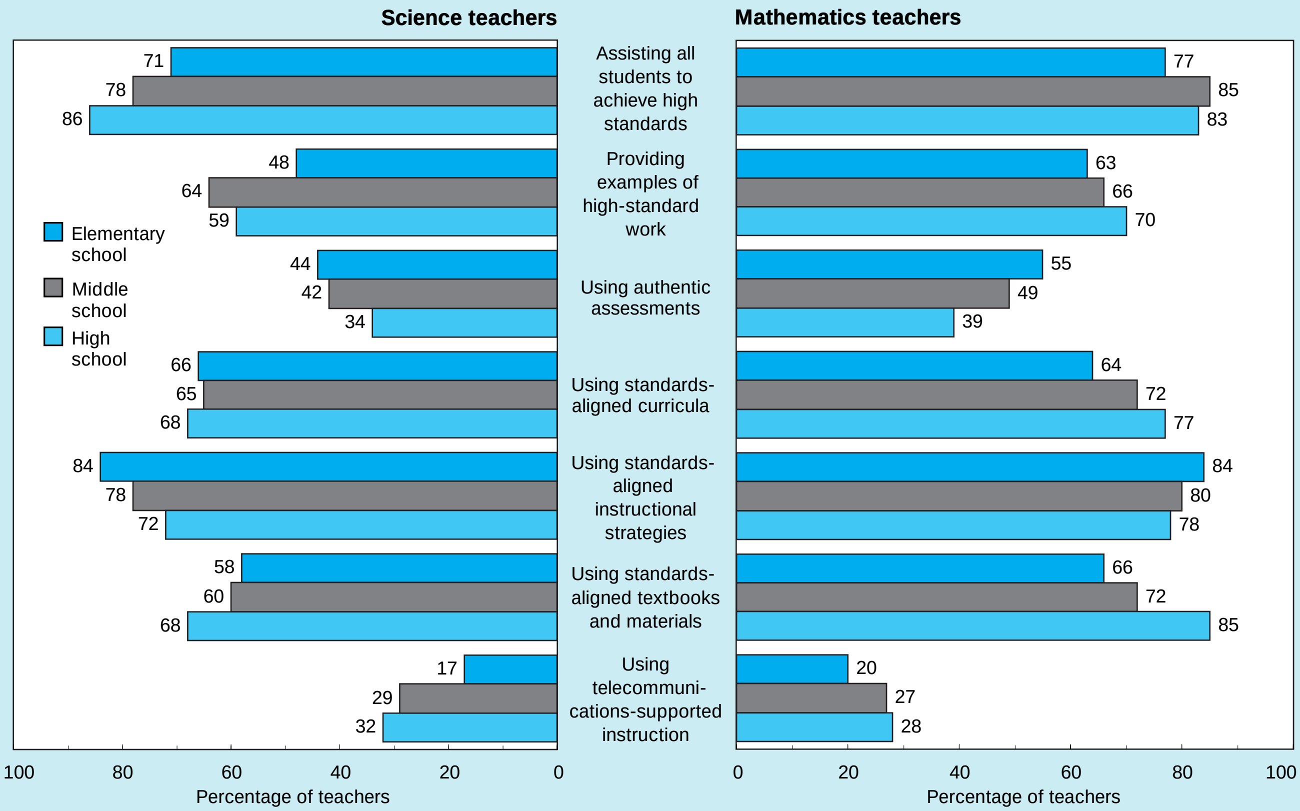
Are Teachers Knowledgeable About the Standards?

In a 1995 survey of teachers, 85 percent of eighth grade mathematics teachers reported being "fairly" or "very" familiar with the *Curriculum and Evaluation Standards for School Mathematics* of the National Council of Teachers of Mathematics. Approximately 26 percent of eighth grade science teachers reported being "very" or "fairly" familiar with *Benchmarks for Science Literacy* of the American Association for the Advancement of Science. The numbers might have been higher if teachers had been asked about standards published by the National Science Teachers Association, an organization to which many science teachers belong (Williams et al. 1997). However, it should be noted that neither of these sets of science standards realized the same levels of visibility and acceptance by the science teaching community as was true of the mathematics standards within the mathematics teaching community.

There are indications that U.S. teachers believe they are implementing some aspects of standards-based instruction. A 1996 survey asked teachers to report on the kind of reform activities they are implementing in their classrooms. The seven-item list of activities included assisting students to reach high standards, using curriculum materials aligned with standards, and using authentic assessments. (See figure 1-18.) Except for using authentic assessments and telecommunications to support instruction, in the majority of cases, mathematics and science teachers at all three levels of schooling believed they were implementing each of the activities included in the survey (NCES 1997d).

Figure 1-18.
Percentage of science and mathematics teachers implementing reform activities in their classes: 1996



SOURCE: National Center for Education Statistics, *Status of Education Reform in Public Elementary and Secondary Schools: Teachers' Perspectives* (Washington, DC: U.S. Department of Education, 1997), forthcoming.

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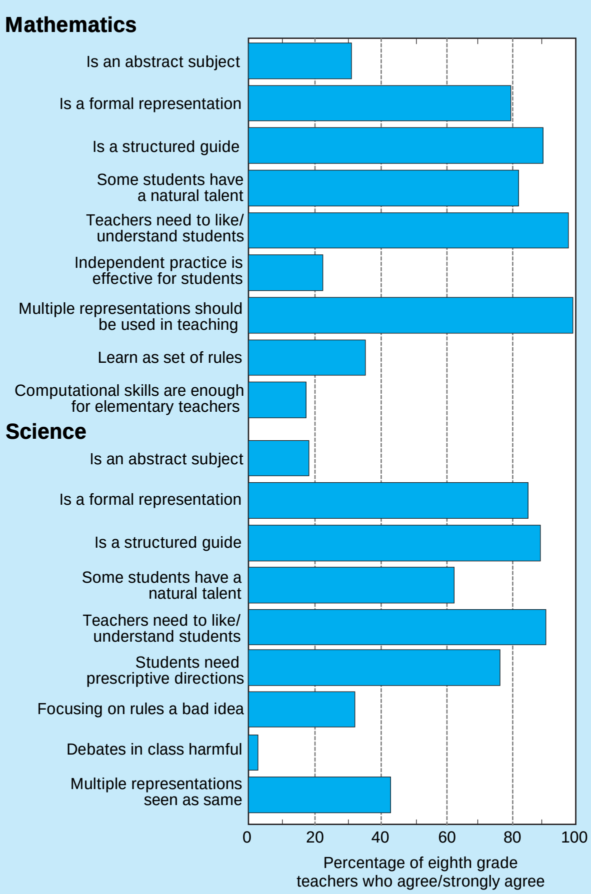
only 32 percent thought focusing on rules might be a bad idea. (See figure 1-19.)

There is substantial agreement between mathematics and science teachers on the aptitudes and skills students need to succeed in learning mathematics and science. Over 80 percent of mathematics and science teachers consider it very important for students to understand concepts, to understand how the subjects are used in the real world, and to be able to support their results and conclusions.

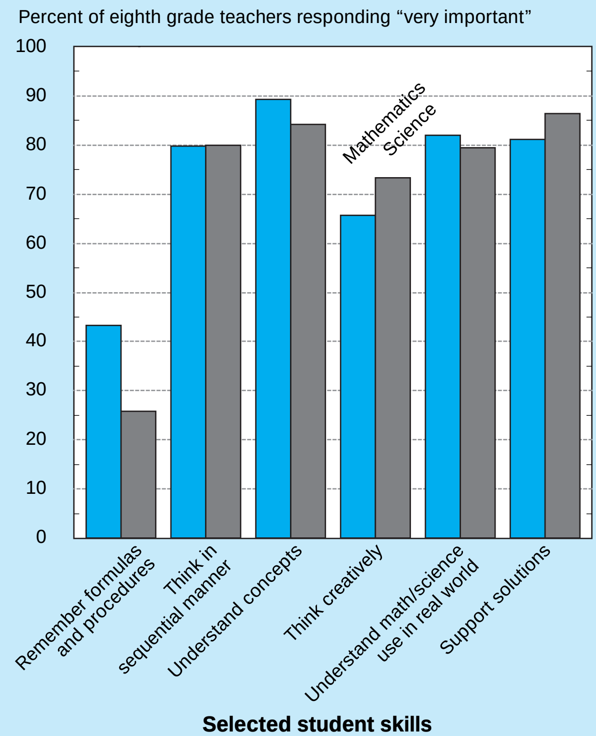
There are some areas of difference in these views. Fewer mathematics teachers (65 percent) than science teachers (73 percent) consider creative thinking very important. However, the biggest difference in views centers on the importance of students remembering formulas and procedures. Over 40 percent of mathematics teachers believe that it is important for students to memorize formulas, compared with 26 percent of science teachers. (See figure 1-20.)

Figure 1-19.
Teacher beliefs about the nature and teaching of mathematics and science: 1994-95



See appendix table 1-18. *Science & Engineering Indicators – 1998*

Figure 1-20.
Teacher perceptions of student skills required for success in mathematics and science: 1994-95



See appendix table 1-19.

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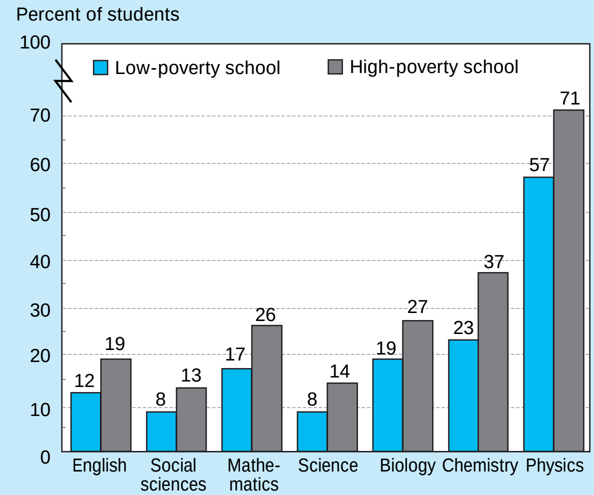
Out-of-Field Teaching

Information about the academic preparation of the teaching force and their views and attitudes toward teaching and learning do not tell the complete story of teachers' qualifications. All too frequently, teachers are assigned to classes outside their fields (Ingersoll 1996). The problem is particularly acute in mathematics. In the 1990/91 school year, students were less likely to have a qualified teacher in mathematics than in any other core subject. About 27 percent of students in grades 7 to 12 had a mathematics teacher without at least a minor in mathematics or mathematics education compared with 21 percent in English, 17 percent in science, and 13 percent in social studies. Out-of-field teaching is more common at middle and junior high schools than in senior high schools. In 1991, 32 percent of students in 7th grade science classes had teachers without a major or minor in science or science education, while only 13 percent of 12th graders did. (See appendix table 1-24.)

There are large differences across states in the proportions of mathematics and science teachers who have degrees in these subjects. The percentage of secondary mathematics teachers with a major in mathematics ranges from under 45 percent in Alaska, Delaware, and Washington to over 80 percent in Pennsylvania and the District of Columbia. Similarly, fewer than half of secondary science teachers in Nevada and Louisiana majored in science in college compared with 80 or more percent in 10 states (Blank and Gruebel 1995).

There are also equity issues involved with out-of-field teaching which is more prevalent in high-poverty schools, in low-achieving classes, and in low-track classes (Chaney 1995; Gamoran 1986; and Oakes, Gamoran, and Page 1992). For example, more than one-quarter of students enrolled in secondary school science classes in which students were judged to be low achieving had a teacher without at least a minor in science or science education, compared with fewer than 1 in 10 students in high-achieving classes. Thirty-six percent of students in classes with high minority enrollments had a mathematics teacher without a major or minor in mathematics or mathematics education, compared with 23 percent of students in low minority classes. In addition, students who attend school in high-poverty areas are much more likely to have mathematics and science teachers without at least a minor in these fields than students attending schools in low-poverty areas. (See figure 1-21.) In effect, students who need the most support are left with the teachers least qualified to help them (Darling-Hammond 1994a; Oakes 1990; and Weiss, Matti, and Smith 1994).

Figure 1-21.
Percentage of public secondary students taught by teachers without at least a minor in the field, by school poverty enrollment: 1993-94



NOTE: In a low-poverty school, 0 to 5 percent of students are eligible for free or reduced-price lunch; in a high-poverty school, 41 to 100 percent of students are eligible for free or reduced-price lunch. The percentages for biology, chemistry, and physics represent students taught by teachers without at least a minor in those particular fields.

SOURCE: National Center for Education Statistics, *The Condition of Education 1996*, NCES 96-304 (Washington, DC: U.S. Department of Education, 1996).

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Reform of the Teaching Profession

Many efforts in the last decade to bring about systemic, standards-based changes in schools have focused on the professionalization of teaching. The logic underlying this approach is that upgrading the profession will increase teachers' commitment and motivation. This will in turn result, it is believed, in better teaching, with the final outcome being improved student learning. A variety of proposals have been offered for improving the status and professional credentialing of teachers. The most ambitious of these proposals seek changes in how teachers are prepared, licensed, and supported throughout their careers (see, for example, Carnegie Forum on Education and the Economy 1986, and National Commission on Teaching and America's Future 1996).

The National Commission on Teaching and America's Future, for example, recommends:

- organizing teacher education and professional development programs around the standards;
- developing extended graduate level teaching programs that offer year-long internships, similar to those offered in the medical profession, to provide closely supervised practice that is tied to coursework; and
- creating stable, high-quality professional development services to support teachers.

Efforts are under way to bring about each of these changes. Some of these initiatives have focused primarily on teacher preparation. The Holmes Group, which was formed by college deans of education, proposed that prospective teachers be required to devote four years of undergraduate study to academic content in their chosen major, and that professional preparation in teaching be postponed to a fifth or sixth year (Holmes Group 1986). Year-long internships, two-year induction periods, and professional development schools are all variations on this basic idea aimed at providing prospective teachers with both better academic preparation and more classroom experience before licensing.

Other efforts have focused on development of standards to guide the profession. The National Board for Professional Teaching Standards has developed standards for accomplished teaching, created performance-based certification exams to identify accomplished teachers, and established a professional board to oversee operation of the system (NBPTS 1991). The Interstate New Teacher Assessment and Support Consortium (INTASC), which was formed by a consortium of state education agencies, higher education institutions, and national educational organizations, has focused on the other end of the continuum: new teachers. INTASC has begun to develop standards and performance-based assessments useful for judging competent entry-level teaching and for guiding the professional development of early career teachers (INTASC 1991).

Both sets of teachers' standards are compatible with each other, and both are directly linked to the national standards for student performance in specific content areas. The standards for new teachers developed by INTASC have been adopted or adapted for use by 14 states and are being used in several additional states as a basis for evaluating their systems for licensing (INTASC 1994).

Policy efforts also have been initiated to infuse standards-based conceptions of teacher preparation into higher education and teacher training institutions. Many educators view the process of program accreditation as the most effective lever for bringing about desired changes. The National Council for the Accreditation of Teacher Education, which has accredited teacher education programs for many years in cooperation with state agencies, has taken steps in this direction. Recently, it has incorporated performance standards developed by the aforementioned INTASC in the program approval process (Darling-Hammond 1994a).

Conclusion

The central question motivating this chapter is whether the K-12 education system in the United States is doing a good job of providing students with a solid foundation in mathematics and science in order to prepare them for work or continuing study, or simply to be literate members of society.

The answer depends on the perspective taken. From the perspective of curriculum, national and cross-national studies give somewhat different answers. National trend studies suggest that U.S. schools are doing a better job of addressing long-standing inequities in the mathematics and science preparation provided to students in different demographic groups. Compared with the late 1970s and early 1980s, higher proportions of male and female students now complete the core college preparatory courses in mathematics and science, and more black and Hispanic students do so as well. On the other hand, as recently as 1994, a significantly larger fraction of white than black and Hispanic students completed advanced courses in mathematics and science, and more male than female students completed physics. Therefore, there are still substantial inequities to be overcome.

International comparisons suggest that U.S. curricula are lacking in depth and focus. The content of the science curriculum is within the international norms for grades 4, 8, and 12. But relative to science curriculum documents and textbooks in other countries, U.S. schools provide too much repetition, too many topics to be learned, and too little coverage of core science topics.

These limitations are even more characteristic of the mathematics curriculum. There are indications as well that at least the eighth grade mathematics curriculum is pitched at a lower level than in other countries. U.S. curriculum guides and textbooks emphasize topics related to whole numbers and fractions while in most other countries, students are studying more topics in geometry and algebra. Cross-national observations of what takes place in eighth grade mathematics classrooms confirm these findings. Lesson goals and the activities provided to support those goals reflect quite limited cognitive expectations. More often than not, the goal is for students to learn specific skills rather than develop a deep understanding of mathematics.

From the perspective of achievement, national and cross-national studies again point to somewhat different conclusions. Following declines in the 1970s, the performance of U.S. students improved in basic skill areas. Nine- and 13-year-olds are scoring higher on mathematics and science assessments than they did in 1973, while 17-year-olds' performance in 1996 was about the same as in 1973. Although progress has not been substantial in the 1990s, U.S. students have lost no ground. Achievement also improved from 1990 to 1996 in mathematics assessments geared to national mathematics standards. And analyses of the performance of girls and boys in the 1990s show few meaningful differences.

But students of different demographic backgrounds are not achieving at the same levels. Asian Americans and Pacific Islanders and white students outperformed black, Hispanic, and Native American students—even when comparisons correct for the disparities in the courses students have taken. Standards-referenced science assessments introduced in 1996 are too different from earlier tests to permit comparisons with earlier years. But the same pattern of ethnic differences was observed in science as in mathematics.

Findings from the most recent international studies of achievement are mixed, depending on subject matter and grade. Better performance was demonstrated by U.S. fourth grade than eighth grade students when compared with other countries. They scored above the international average in mathematics and well above the international average in science. Eighth grade students performed above the international average in science but well below the international average in mathematics. Because of differences in the ways earlier international comparisons were conducted, it is difficult to tell if U.S. students are performing comparatively better or worse than they did in previous years. Although the relative standing of U.S. fourth grade students in science has gone up compared with earlier studies, it cannot be said definitively that this represents a real change in standing.

Returning to the original question: what do these findings suggest about the progress and quality of U.S. education? First, they show that the mathematics and science education of students is improving somewhat in terms of equity and excellence—the dual goal of educational reforms. Second, there is much room for improvement, and we are still far from reaching our national goal of being first in the world in mathematics and science. Third, students are not yet performing at the levels of expectation recommended by the mathematics and science standards. Fourth, the curricula could better define and focus on core content in mathematics and science as recommended by the standards. And fifth, teachers could better help students develop a genuine understanding of mathematics and science by engaging them in active tasks that challenge their intellectual capabilities. On the whole, although progress has been made, our schools and school districts will have to do much more if students are to be well-prepared for a future that demands that we, as a nation, have a citizenry solidly grounded in mathematics and science.

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